Lecture # 04 Classic Pressure Measurement Instrumentation

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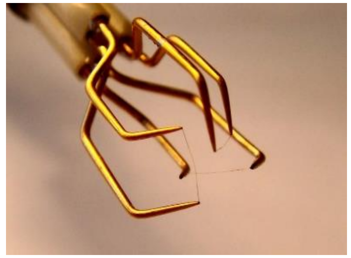
❑ Various measurement Techniques for Thermo-Flow Studies

Velocity, temperature, pressure, density (concentration), etc…

Thermal-Fluids measurement techniques

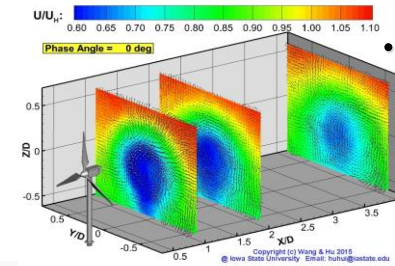


•Hotwire probe

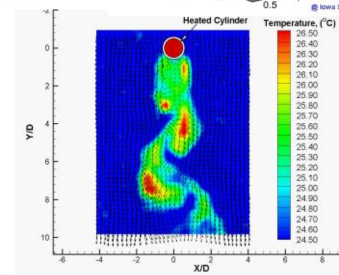
•Thermocouples

Intrusive techniques

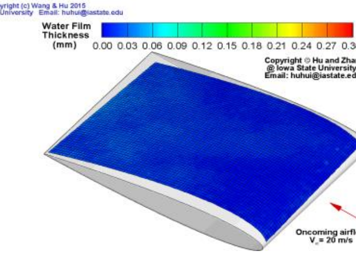
- Pitot probe
- hotwire, hot film
- thermocouples
- etc…



• Stereoscopic PIV



• MTV & MTT



• DIP measurements

Non-intrusive techniques

particle-based techniques

- Laser Doppler Velocimetry (LDV)
- Planar Doppler Velocimetry (PDV)
- Particle Image Velocimetry (PIV)
- etc…

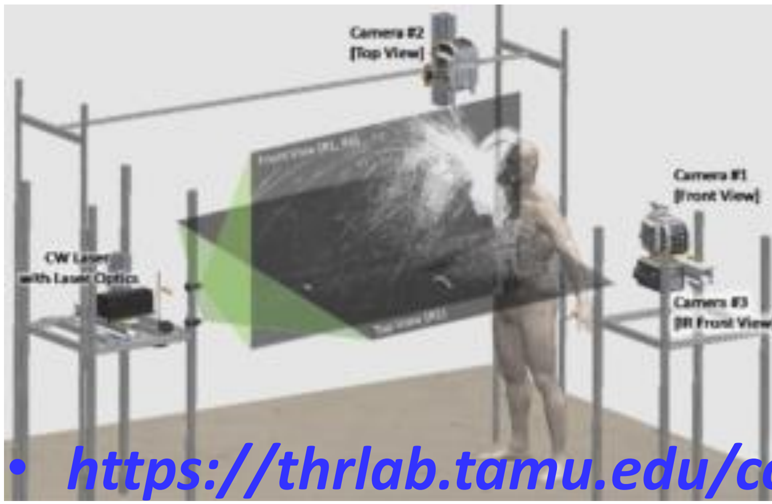
molecule-based techniques

- Laser Induced Fluorescence (LIF)
- Molecular Tagging Velocimetry (MTV)
- Molecular Tagging Therometry (MTT)
- Digital Image Projection (DIP)
- Pressure Sensitive Paint (PSP)
- Temperature Sensitive Paint (TSP)
- Quantum Dot Imaging
- etc …

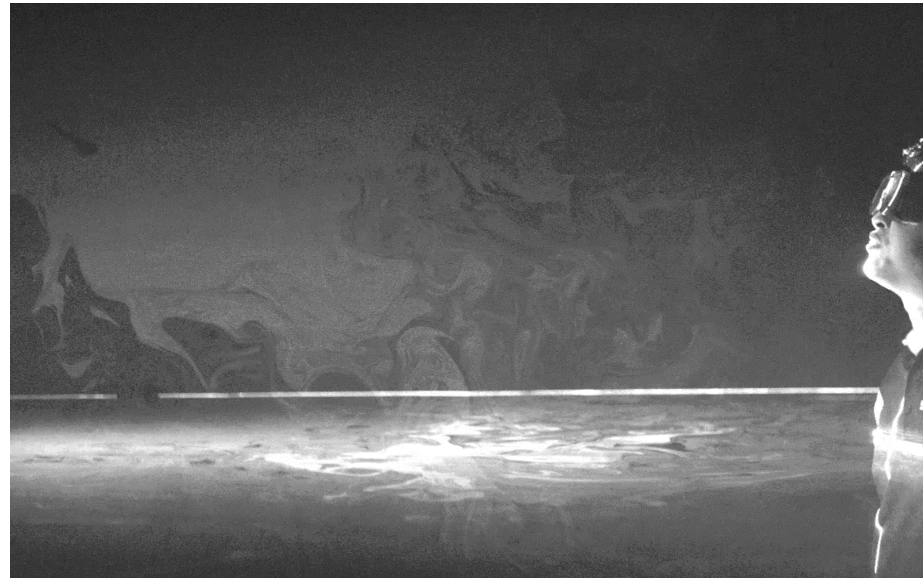
Flow velocity V_f = *Velocity of particles or molecule Tracers, V_{tracer}*

❑ PIV EXAMPLES

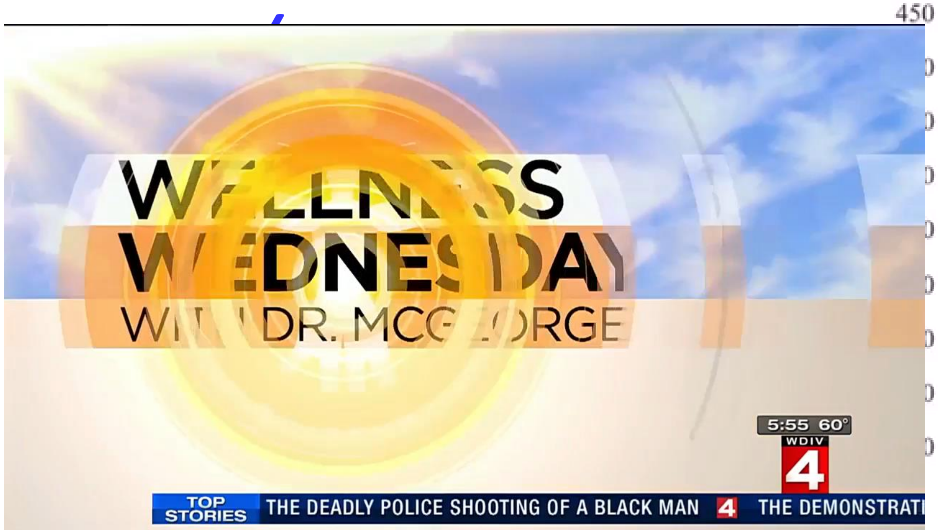
- *A supportive COVID-19 study: Experimental Investigation on a Human Sneeze*



- ***https://thrlab.tamu.edu/covid-***



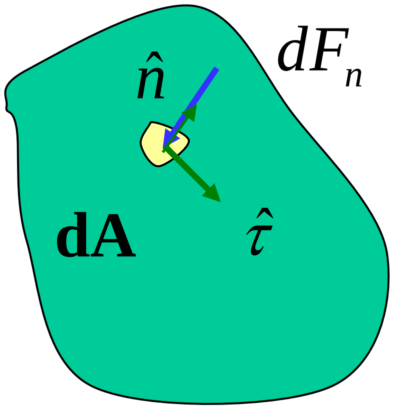
- ***https://www.youtube.com/watch? =9-ui6uFhUx0***

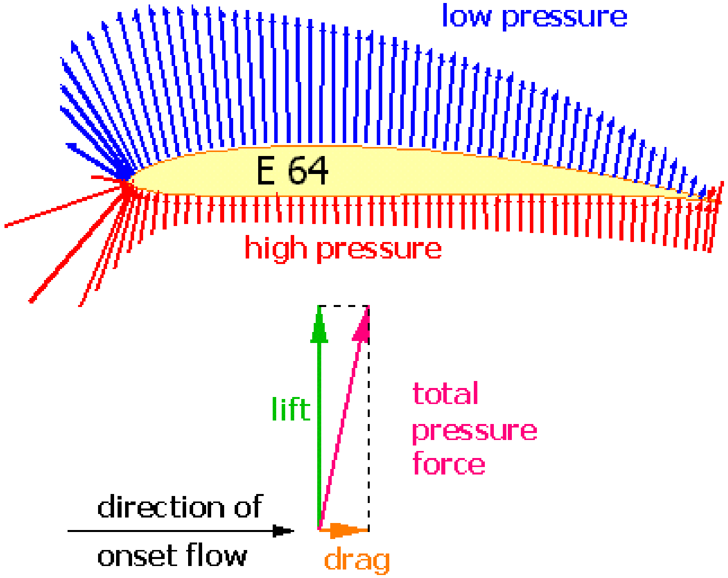


❑ PRESSURE MEASUREMENTS

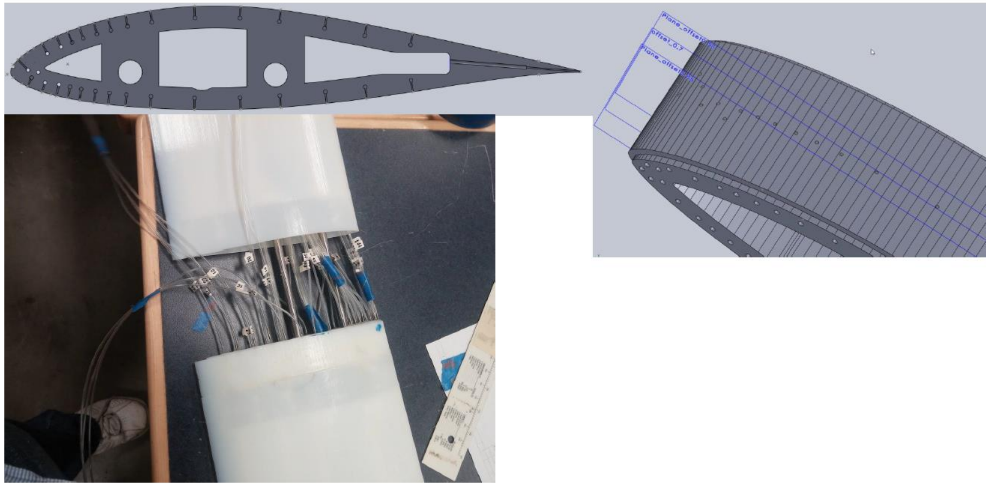
- ***Pressure is defined as the amount of force that presses on a certain area.***
  - ***The pressure on the surface will increase if you make the force on an area bigger.***
  - ***Making the area smaller and keeping the force the same also increase the pressure.***
  - ***Pressure is a scalar***

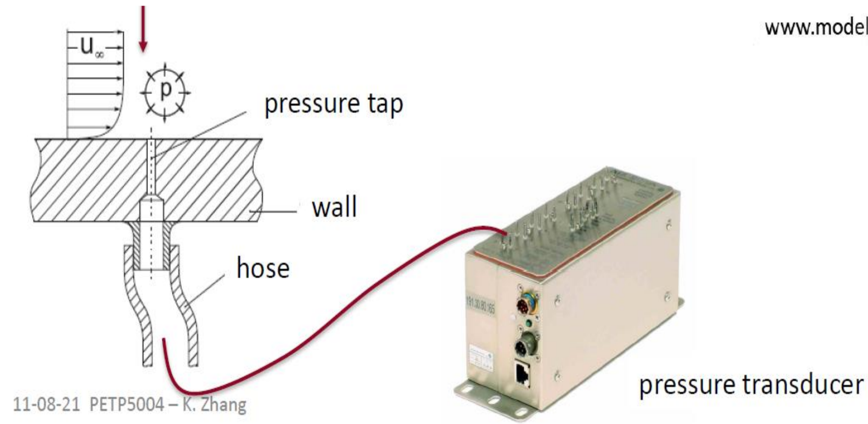
$$P = \frac{F_n}{A} = \frac{dF_n}{dA}$$





❑ Aerodynamic Performance of An Airfoil

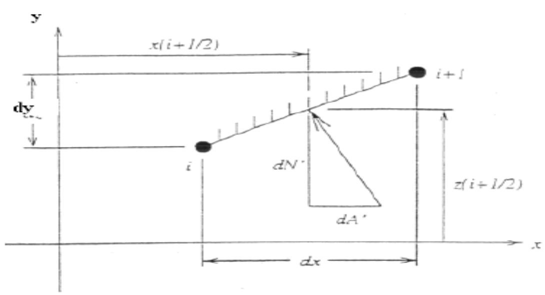




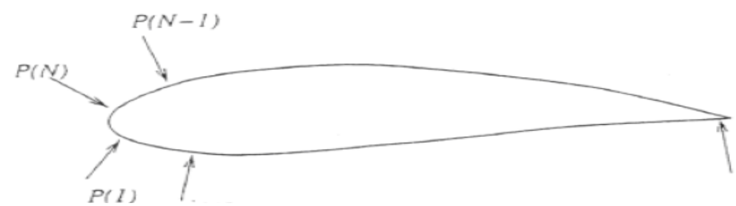
Example of a pressure measurement

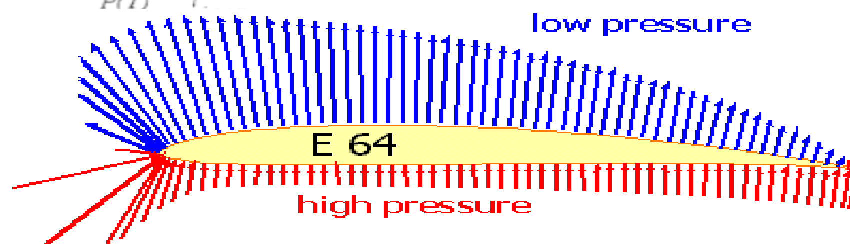
$$\begin{cases} \delta N_i' = p_{i+1/2}\Delta x_i \\ \delta A_i' = -p_{i+1/2}\Delta y_i \\ \delta M_{LE,i}' = -(p_{i+1/2}\Delta x_i)x_{i+1/2} - (p_{i+1/2}\Delta y_i)y_{i+1/2} \end{cases}$$

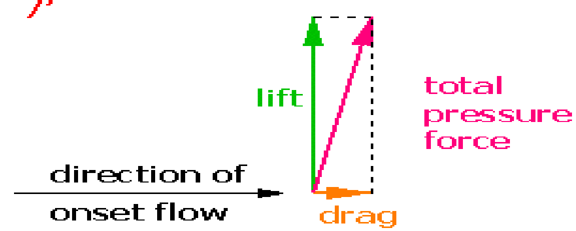
$$\begin{cases} N_i' = \sum_{i=1}^{N} \delta N_i' \\ A_i' = \sum_{i=1}^{N} \delta A_i' \\ M_{LE,i}' = \sum_{i=1}^{N} \delta M_{LE,i}' \end{cases}$$



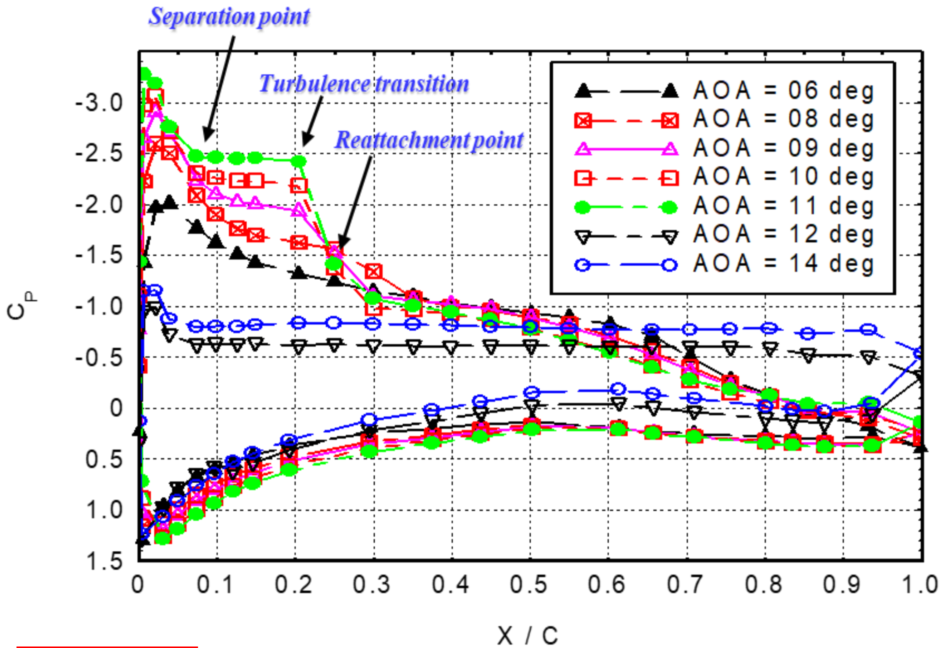
$$\begin{cases} L' = N'\cos\alpha - A'\sin\alpha \\ D' = N'\sin\alpha + A'\cos\alpha \end{cases}$$

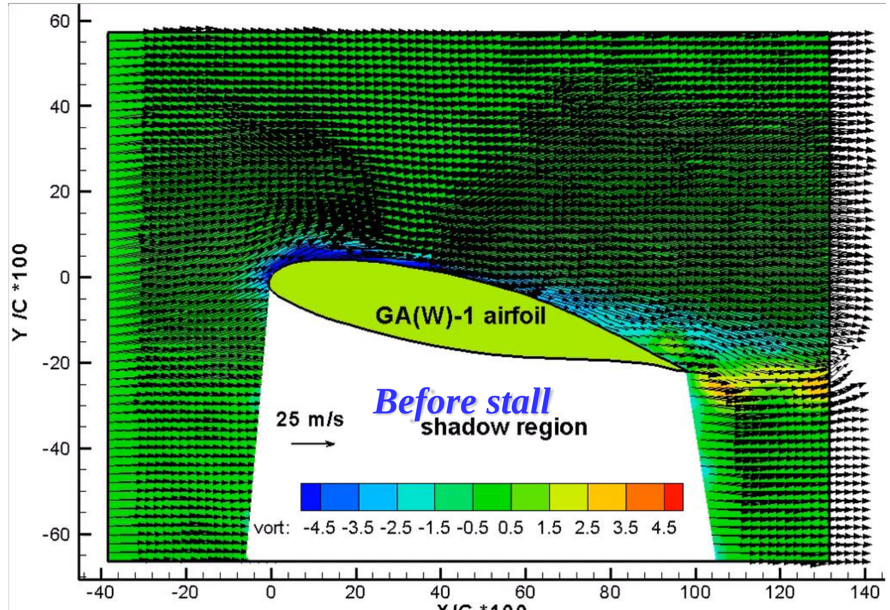




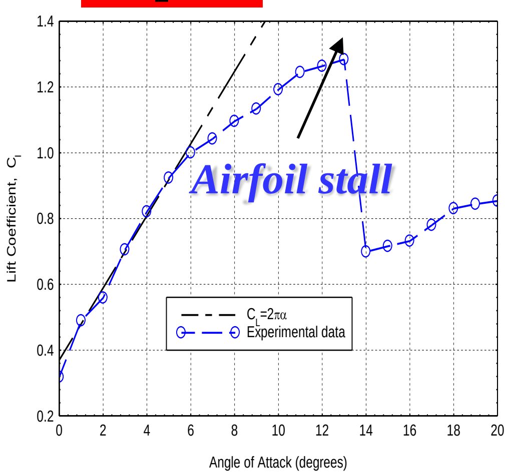


❑ Aerodynamic Performance of An Airfoil

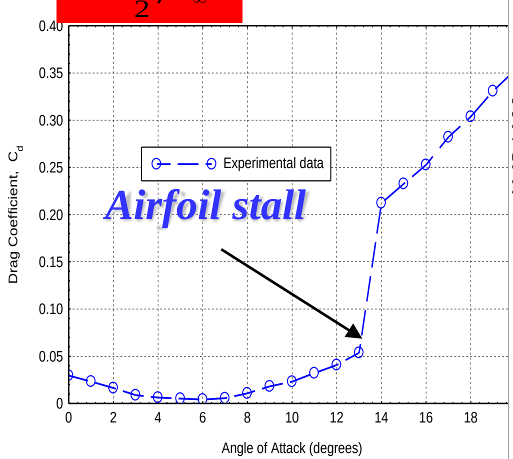


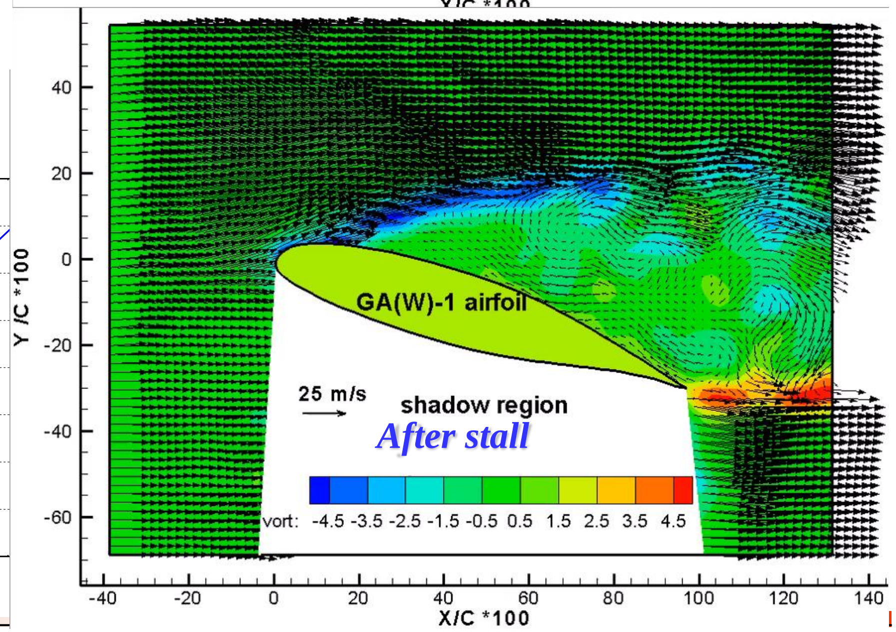


$$C_l = \frac{L}{\frac{1}{2}\rho V_\infty^2 c}$$



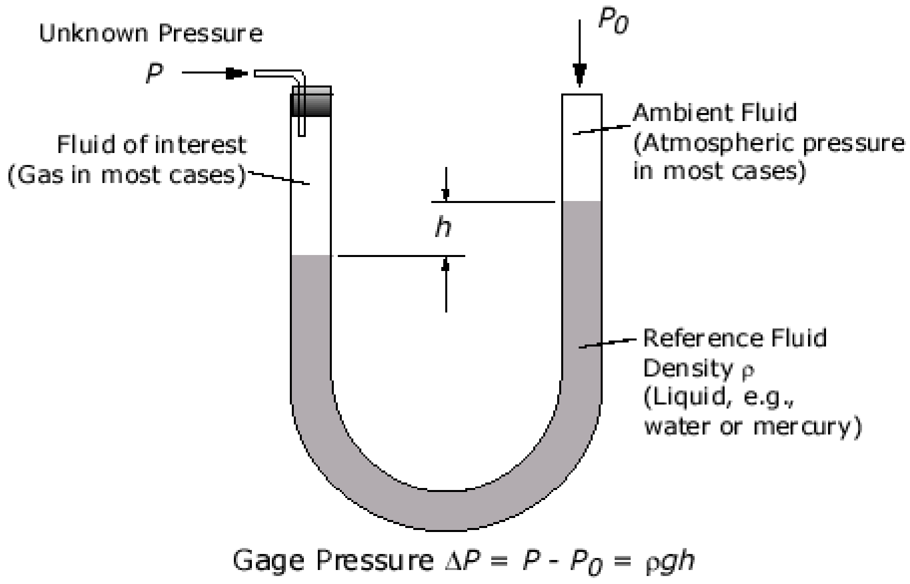
$$C_d = \frac{D}{\frac{1}{2}\rho V_\infty^2 c}$$





❑ PRESSURE MEASUREMENTS

$$P_{gauge} = P_{absolute} - P_{amb}$$

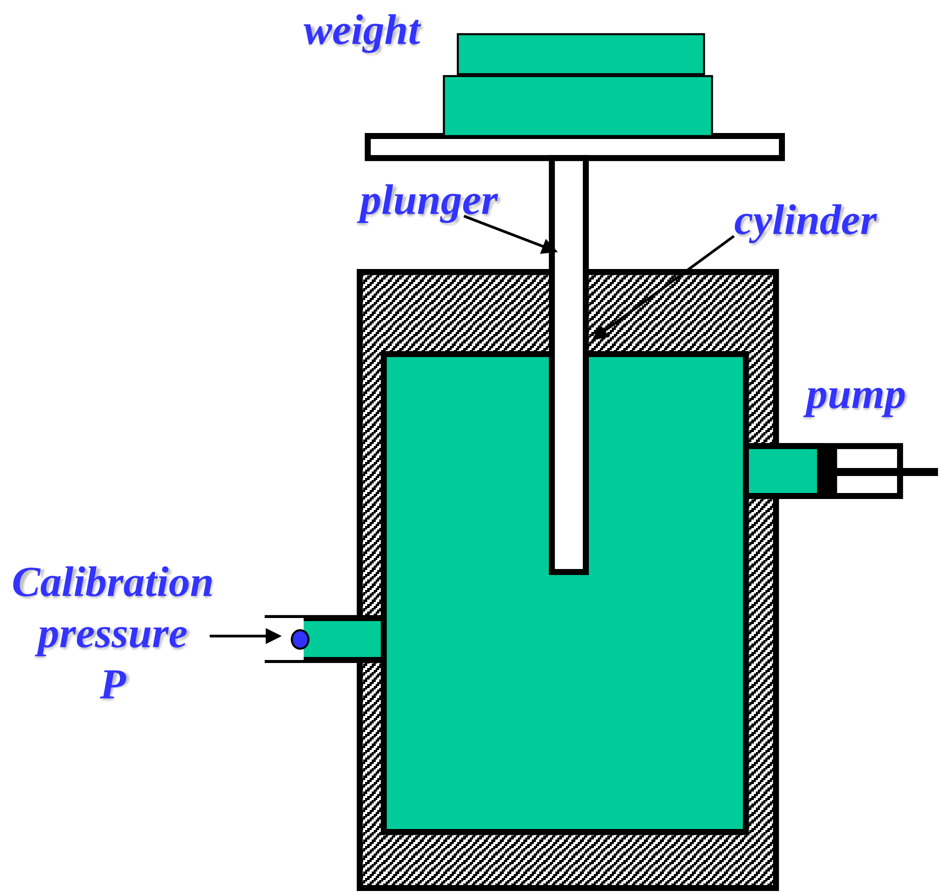


Manometer

❑ MECHANICAL PRESSURE GAUGES -1

Deadweight gauges:

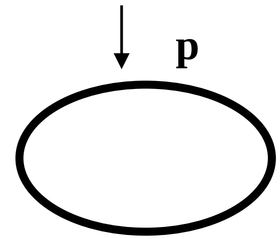
- *High accuracy*
- *Usually used for the calibration of other instruments*
- *Application range : 102~108 pa*
- *Uncertainty is within 0.01% ~0.05% of the reading*



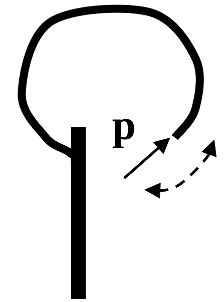
❑ Mechanical Pressure Gauges -2

Elastic-element gauges:

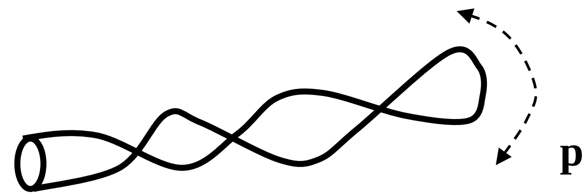
- ***Contain an elastic element that deforms under pressure and creates a linear or angular displacement***
- ***The displacement is either displayed on a dial using purely mechanical linkages or transformed to an electric signal that can be displayed or recorded at will.***
- ***They are usually used for monitoring supply pressure***



Cross sectional shape



Curved Bourdon tube

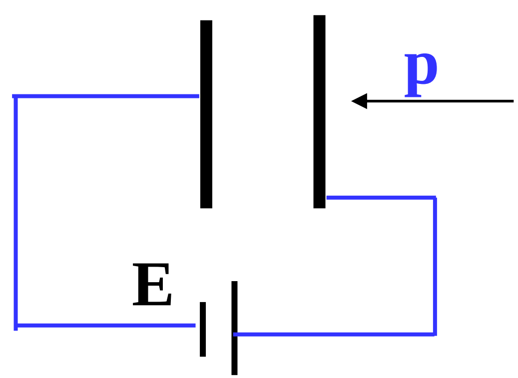


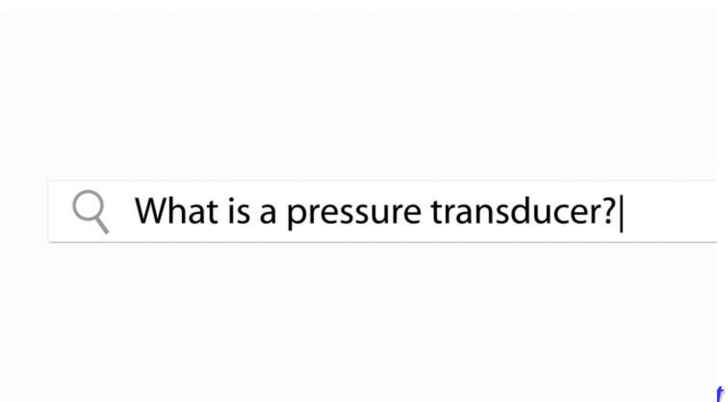
Twisted Bourdon tube

❑ Electrical Pressure transducers

DSA3217 (Shown)

- *These devices provides an electric output signal that is linearly or nonlinearly dependent on the absolute pressure or a pressure difference.*
- *They can be categorized as:*
  - *Molecular transducers:*
    - *Applied pressure or force produces a change (on the molecular level) of an electrical property of material.*
    - *Piezo-electric material such as quartz crystal: change in internal dipole moments of the molecules of the crystal when the pressure or force is applied.*
  - *Parametrical transducers:*
    - *The gross electrical parameter (resistance, inductance, capacitance) of an associate electrical parameter is altered by applied force.*
    - *Variable-capacitance transducer*





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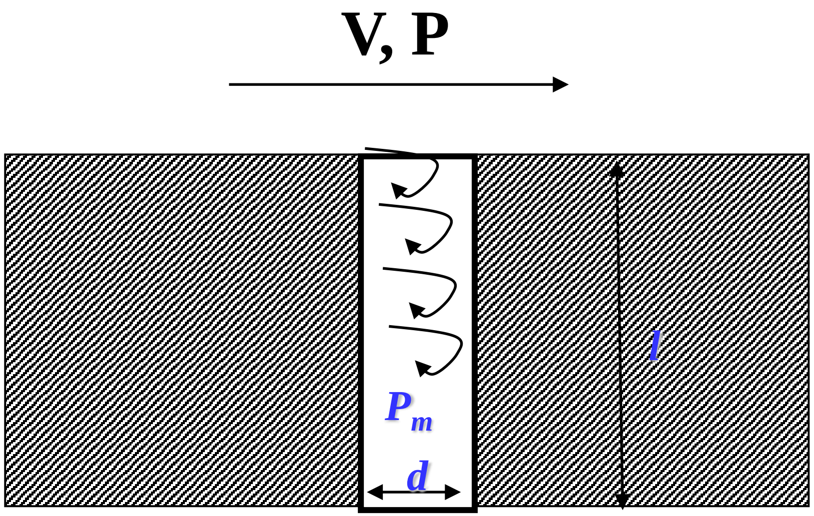
❑ WALL PRESSURE MEASUREMENTS -1

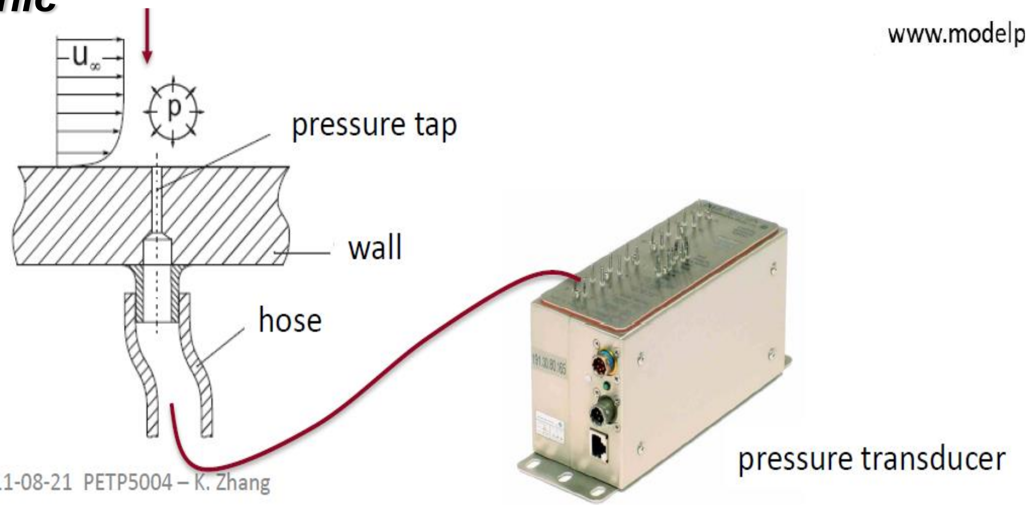
- *Making small orifice (pressure tap) facing the flow.*

$$\Delta p = P_m - P > 0$$



- *Machining small hole could be difficult*
- *d = 0.5~3.0mm in practice*
- *l/d = 5 ~ 15 is commonly used*

- *Potential effect on the wall roughness*
- *Effects of unsteady shock wave, and shock-boundary-layer interactions for transonic and supersonic flows:*
- *PSP method to be introduced later*



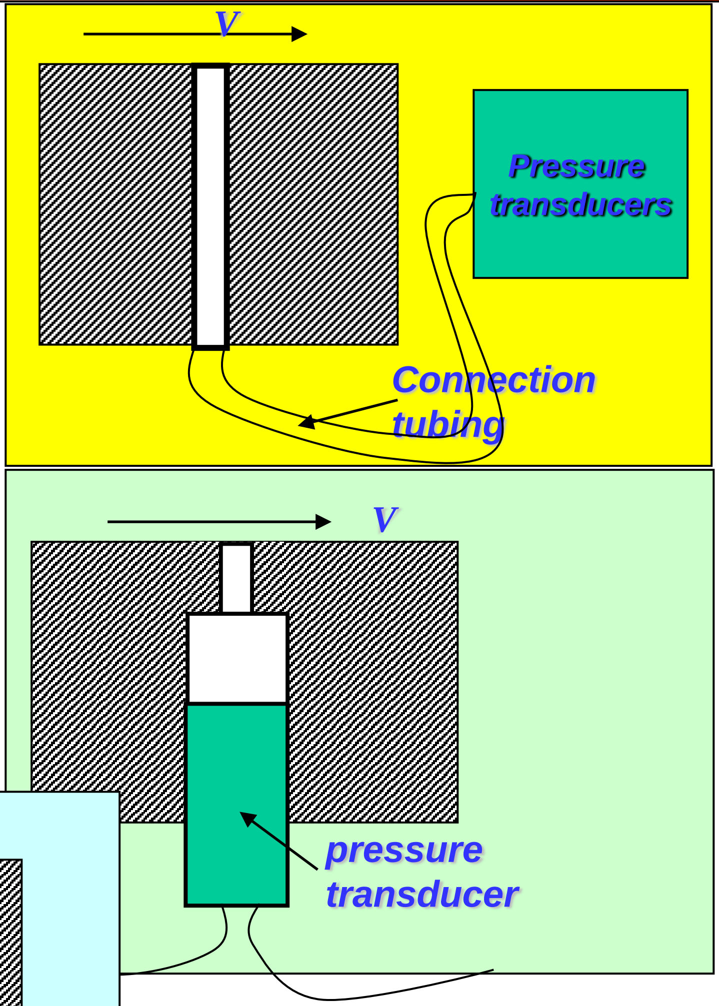
❑ Wall Pressure measurements - 2

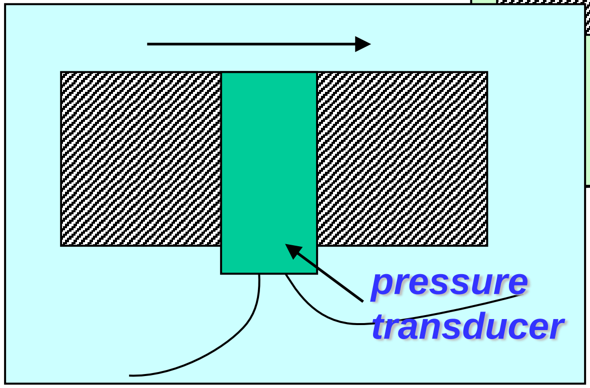
- *For an unsteady flow, the dynamic response of a pressure acquisition system is a key issue!*
  - *Dynamic response of the pressure transducers*
  - *Dynamic response of the connection tubing*

- *Remote connection*
  - *Dynamic response is low*
  - *Spatial resolution is high*

- *Cavity mounting*
  - *Dynamic response is good*
  - *Spatial resolution is high*

- *Flush mounting*
  - *Dynamic response is high*
  - *Spatial resolution is low*

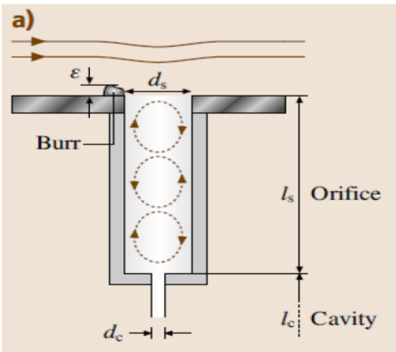




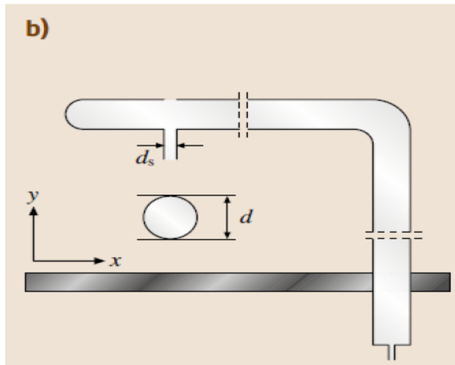
❑ WALL PRESSURE MEASUREMENTS - 2

Pressure tap geometry critical and error:

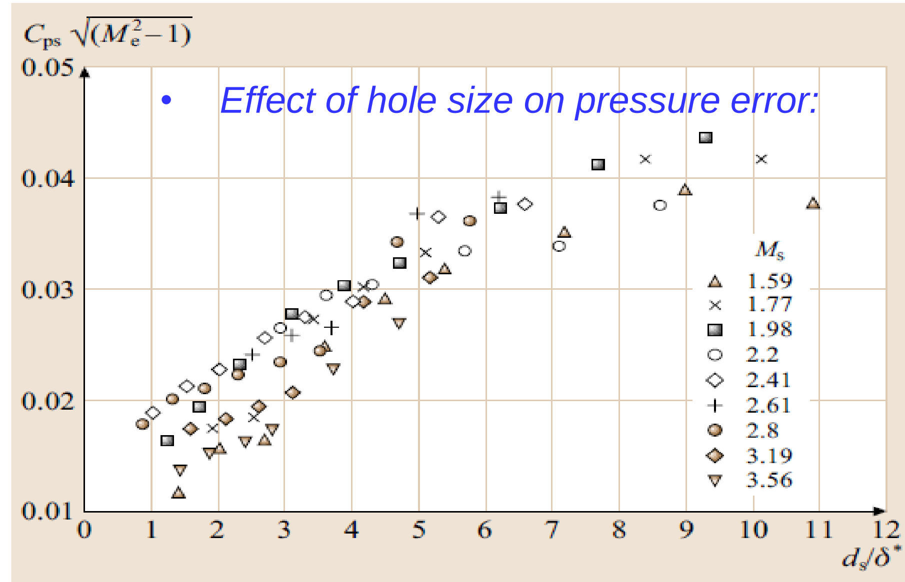
$$P_{wm} = P_w + \Delta P_w \qquad \Pi = \frac{\Delta p}{\tau_w} = f\left(\frac{d_s u_\tau}{\upsilon}, \frac{d_s}{D}, M, \frac{l_s}{d_s}, \frac{d_c}{d_s}, \frac{\varepsilon}{d_s}\right)$$



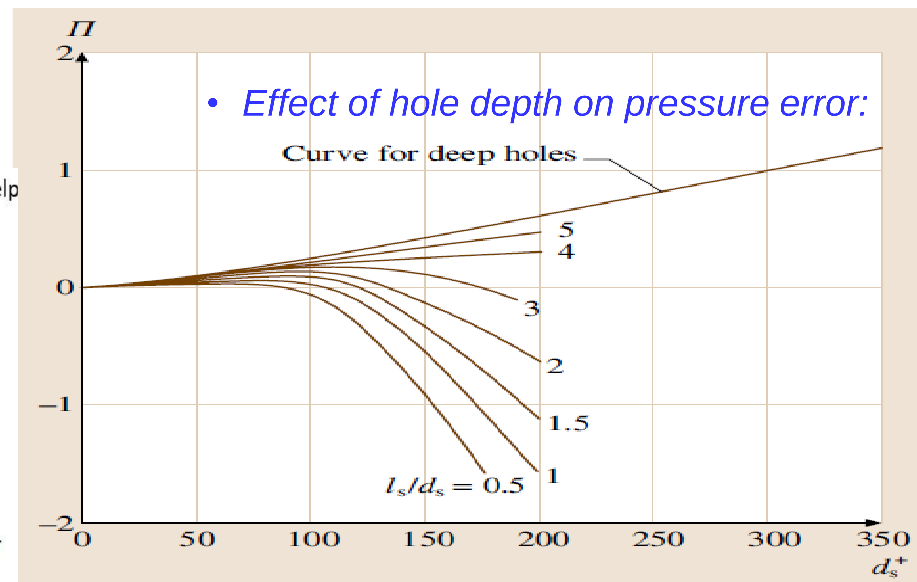
Tropea (2007)

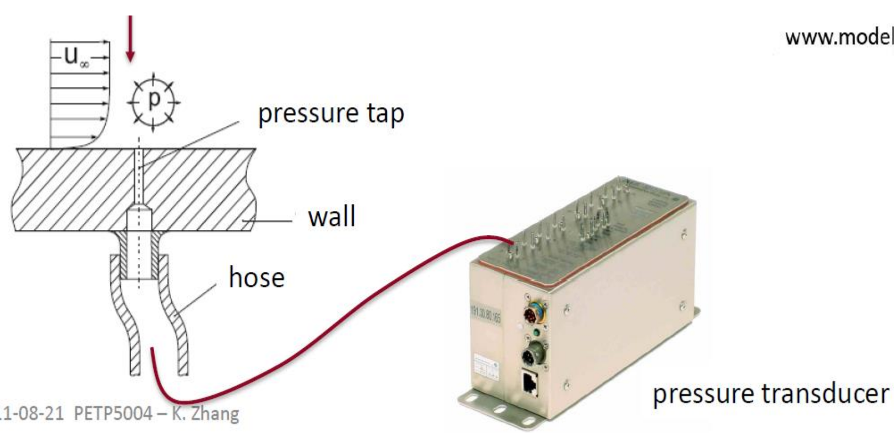


- Effect of hole size on pressure error:



- Effect of hole depth on pressure error:

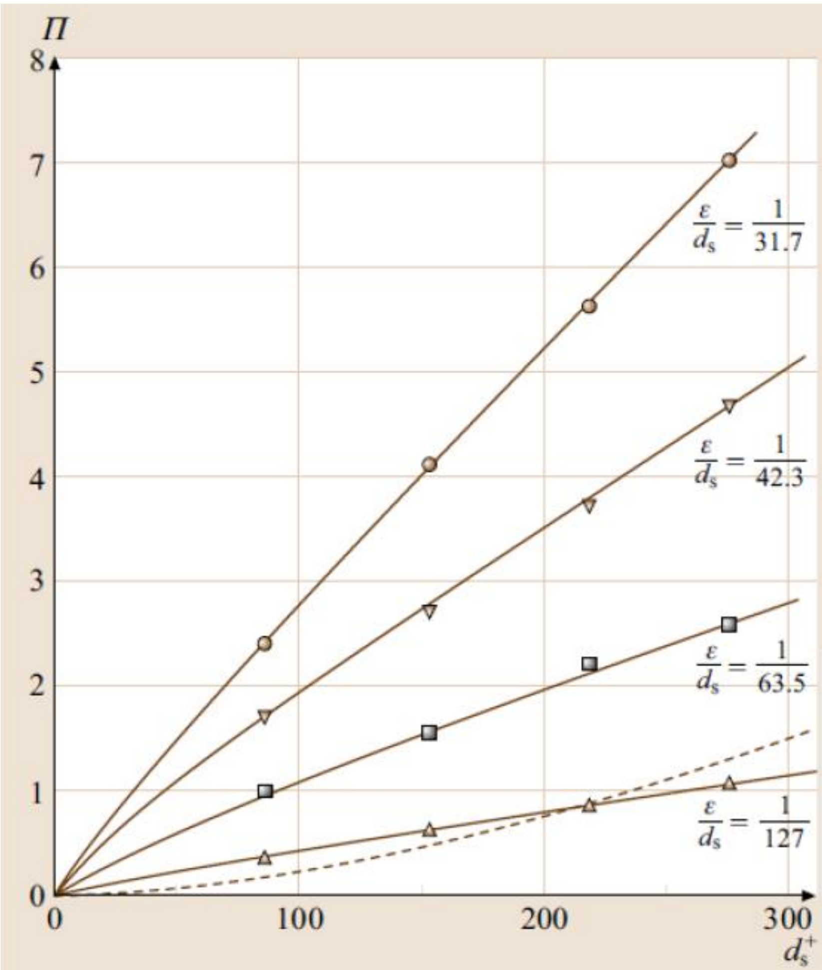


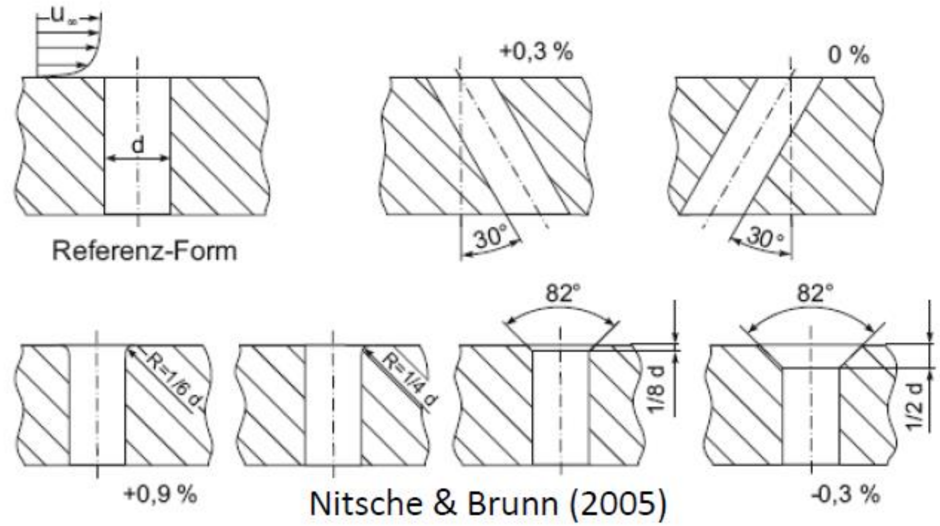


www.modelp

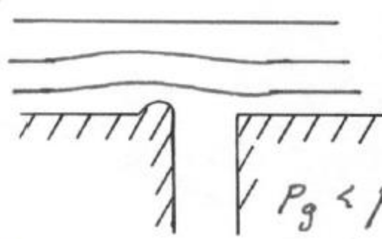
❑ WALL PRESSURE MEASUREMENTS - 2

Effect of condition of orifice edge:

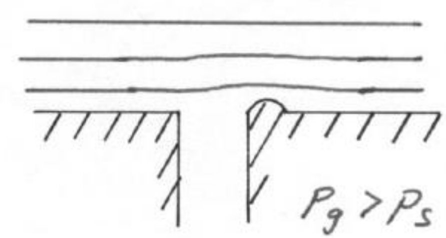




Measured lower than static

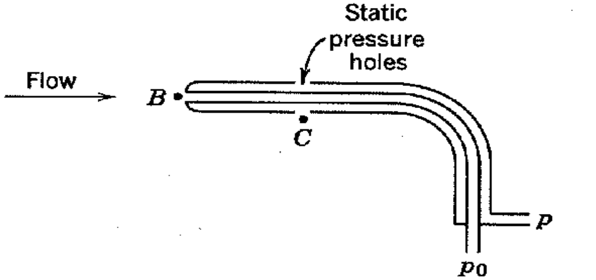


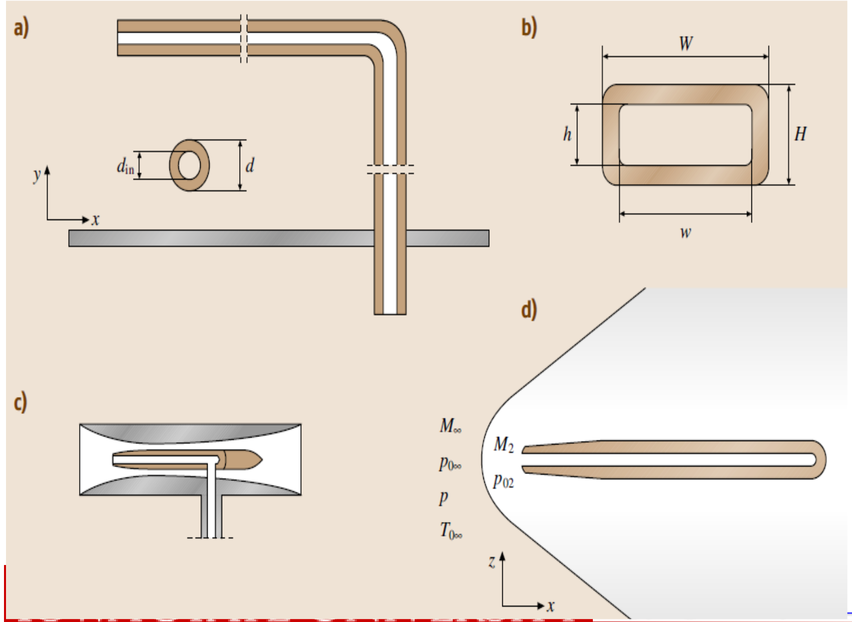
Measured higher than static

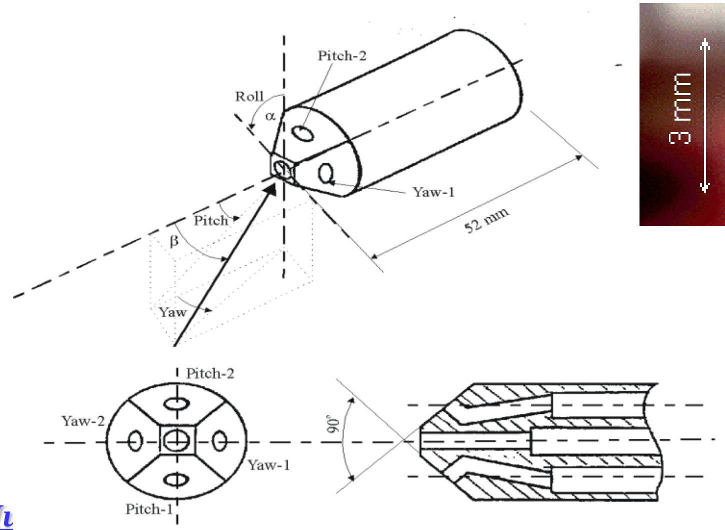


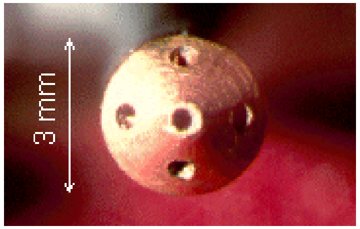
❑ Pressure Measurements inside Flow Field

- *Non-intrusive technique is unavailable for direct pressure measurements*
  - *Based on N-S equation to calculate pressure field using the measured (PIV) velocity field.*
- *Static probe: for static pressure measurements*
- *Pitot probe: for total pressure measurements*
- *Pitot-static probe: for static and total pressures measurements (velocity measurements)*
- *Multi-hole probe:*



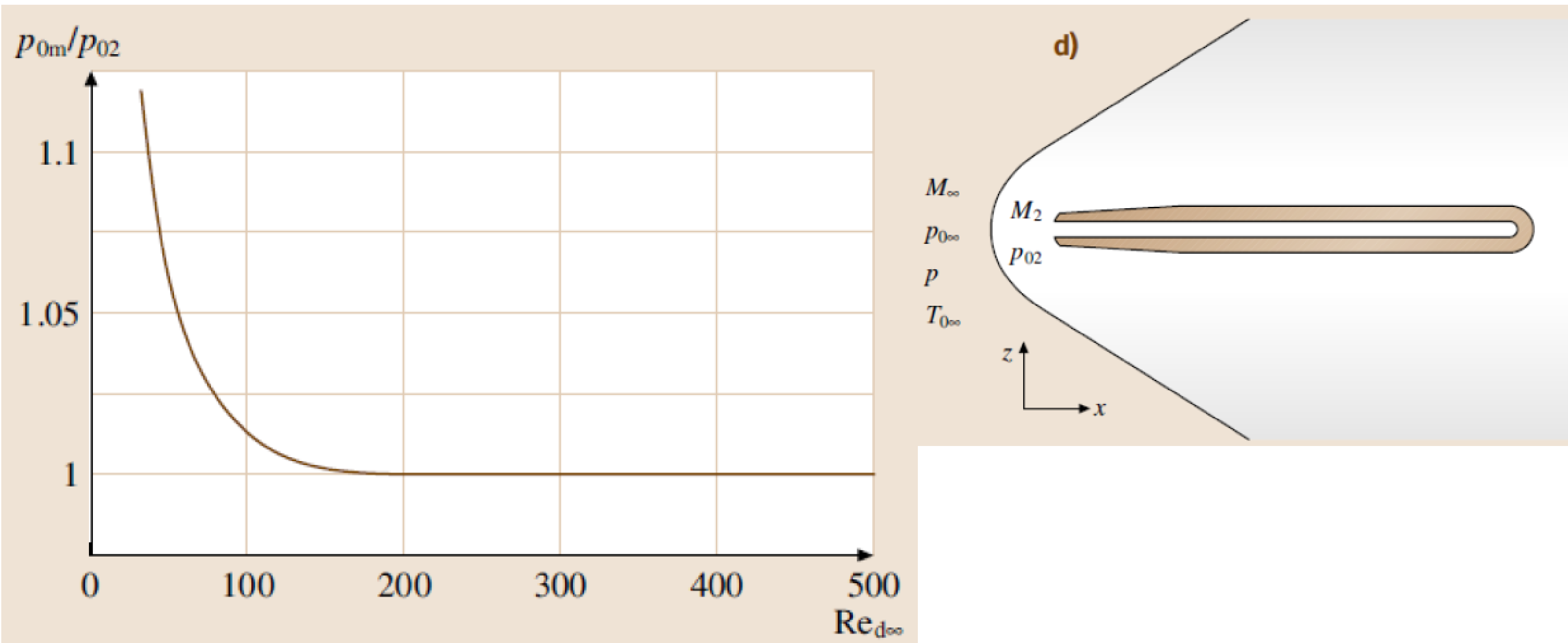






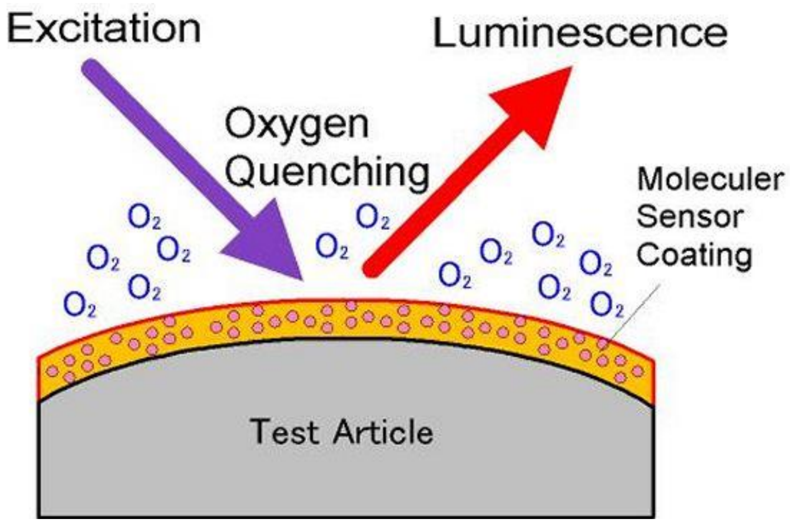
❑ Pressure Measurements inside Flow Field

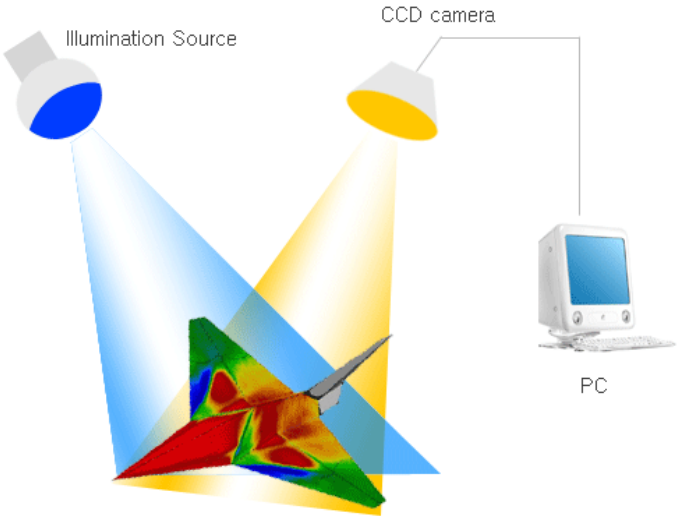
Measurement of total pressure with pitot tubes-influence of shock wave:



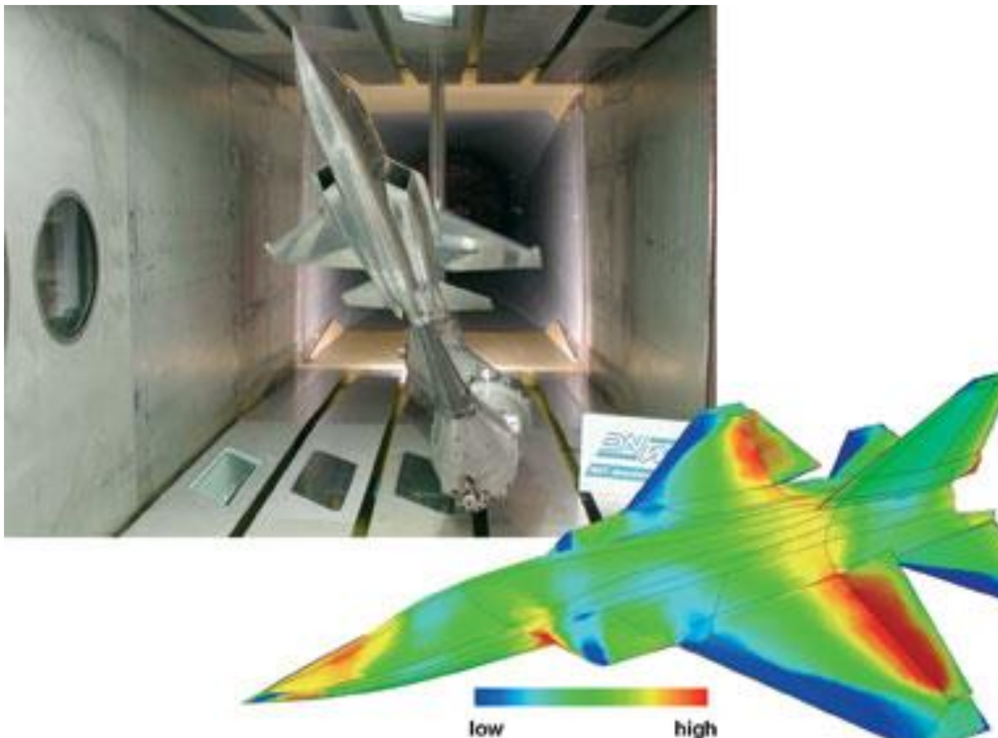
❑ Pressure Sensitive Paint (PSP) technique

- *Composition of Air: 78.08% N_2, 20.95% O_2, 0.93% Ar, 0.03% CO_2, 0.002% Ne, plus lesser amounts of Methane, Helium, Krypton, Hydrogen, Xenon.*
- *The pressure of air can be determined if the particle pressure of oxygen (i.e., oxygen concentration) can be measured.*
- *A typical pressure sensitive paint is comprised of two main parts: an oxygen sensitive fluorescent molecule and an oxygen permeable binder*

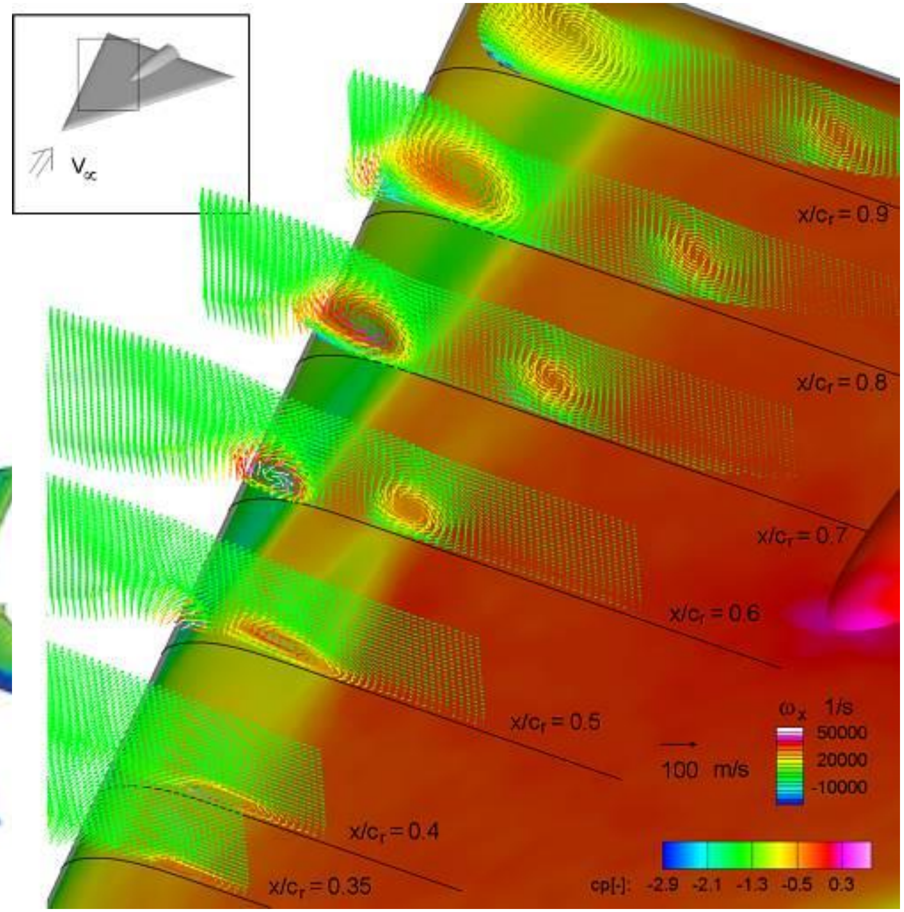




❑ Applications of PSP Technique

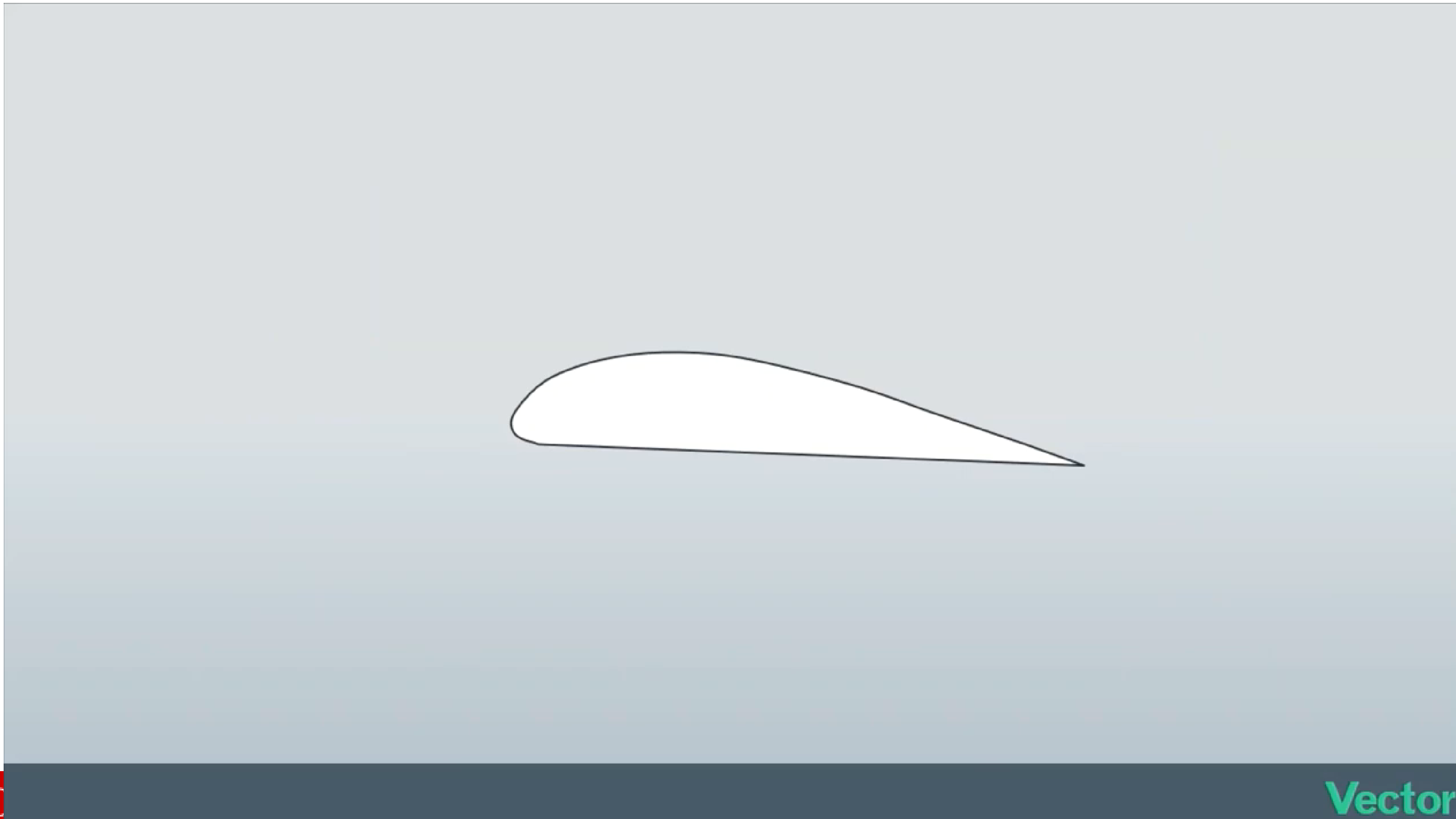


PSP measurement result



PSP combined with PIV

AerE445/AerE545 Lab#01: Surface Pressure Measurement and Hotwire Anemometry Lab



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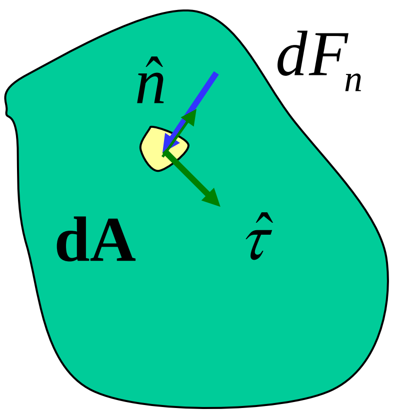
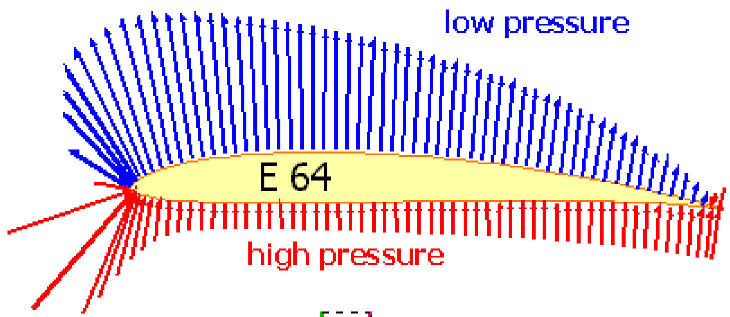
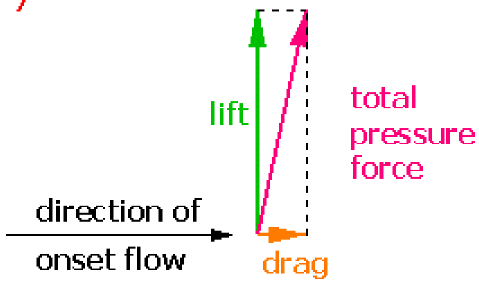
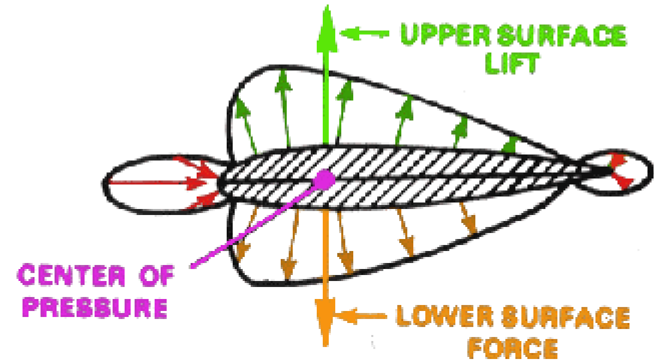
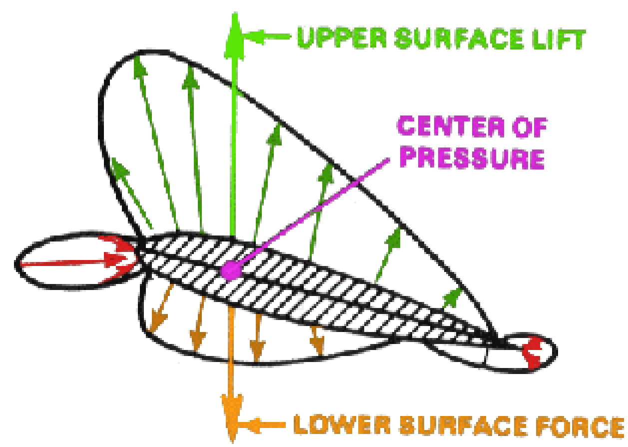






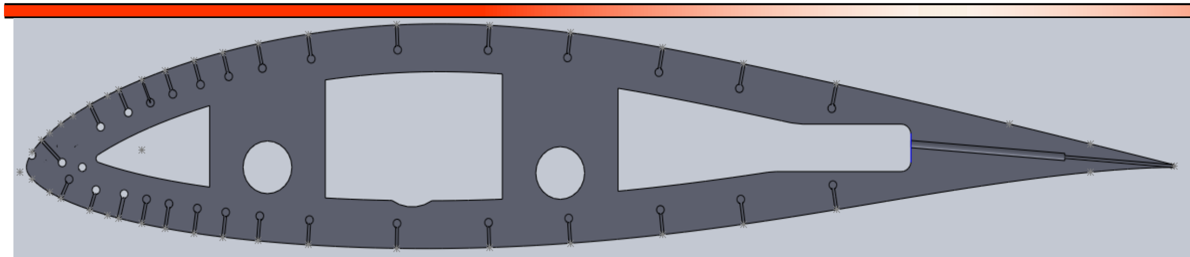


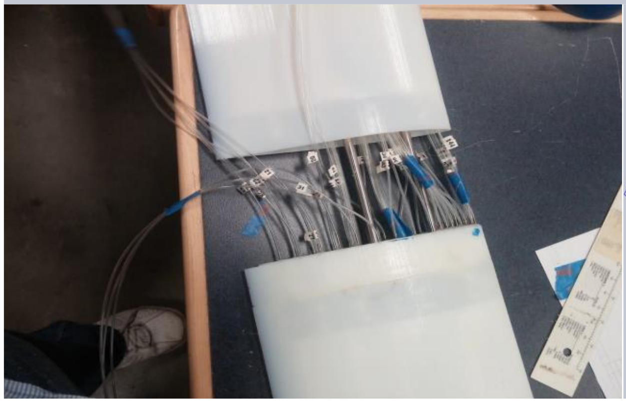
SYMMETRICAL AIRFOIL AT ZERO LIFT

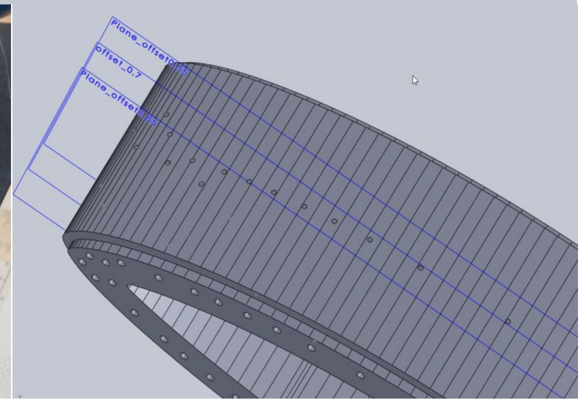


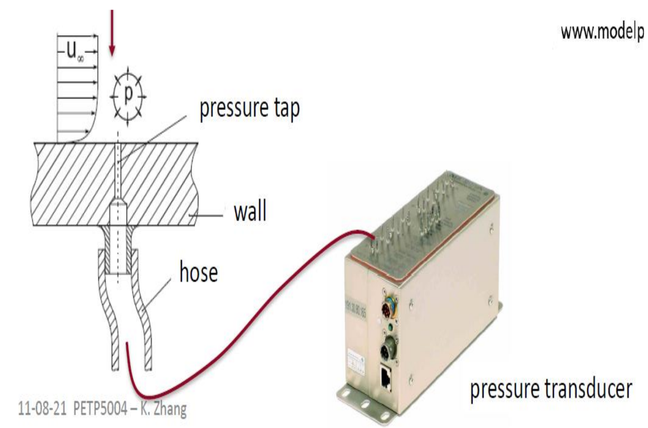
SYMMETRICAL AIRFOIL AT POSITIVE LIFT

❑ Aerodynamic Performance of An Airfoil





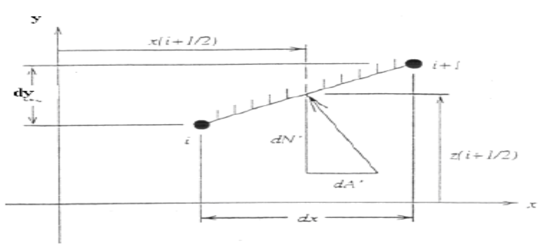




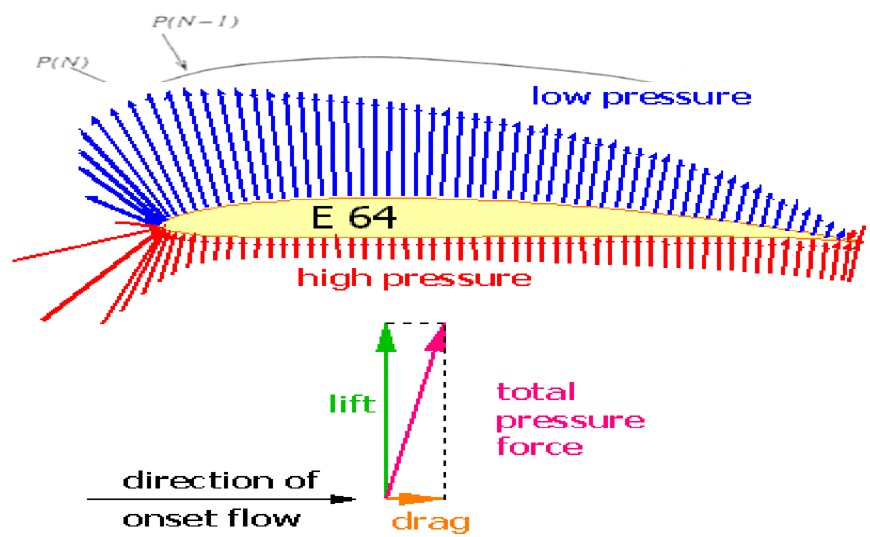
Example of a pressure measurement

$$\begin{cases} \delta N_i' = p_{i+1/2}\Delta x_i \\ \delta A_i' = -p_{i+1/2}\Delta y_i \\ \delta M_{LE,i}' = -(p_{i+1/2}\Delta x_i)x_{i+1/2} - (p_{i+1/2}\Delta y_i)y_{i+1/2} \end{cases}$$

$$\begin{cases} N_i' = \sum_{i=1}^{N} \delta N_i' \\ A_i' = \sum_{i=1}^{N} \delta A_i' \\ M_{LE,i}' = \sum_{i=1}^{N} \delta M_{LE,i}' \end{cases}$$



$$\begin{cases} L' = N'\cos\alpha - A'\sin\alpha \\ D' = N'\sin\alpha + A'\cos\alpha \end{cases}$$



Determination of the Aerodynamic Performance of a Low-Speed Airfoil based on Pressure Distribution Measurements

What you will have available to you for this portion of the lab:

- ***A Pitot probe already mounted to the floor of the wind tunnel for acquiring dynamic pressure throughout your tests.***
- ***A Setra manometer to be used with the Pitot tube to measure the incoming flow velocity.***
- ***A thermometer and barometer for observing ambient lab conditions (for calculating atmospheric density).***
- ***A computer with a data acquisition system capable of measuring the voltage from your manometer.***
- ***The pressure sensor you calibrated last week***
- ***A NACA 0012 airfoil that can be mounted at any angle of attack up to 15.0 degrees.***
- ***Two 16-channel Scanivalve DSA electronic pressure scan***

- *DU-96-W-180 airfoil model with 43 pressure t*

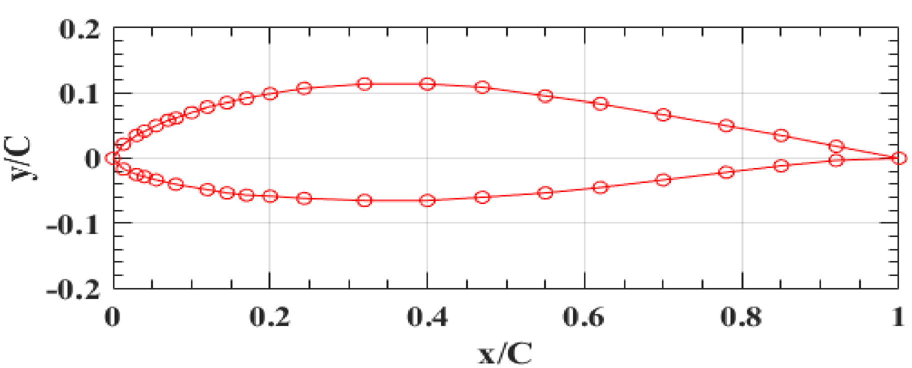
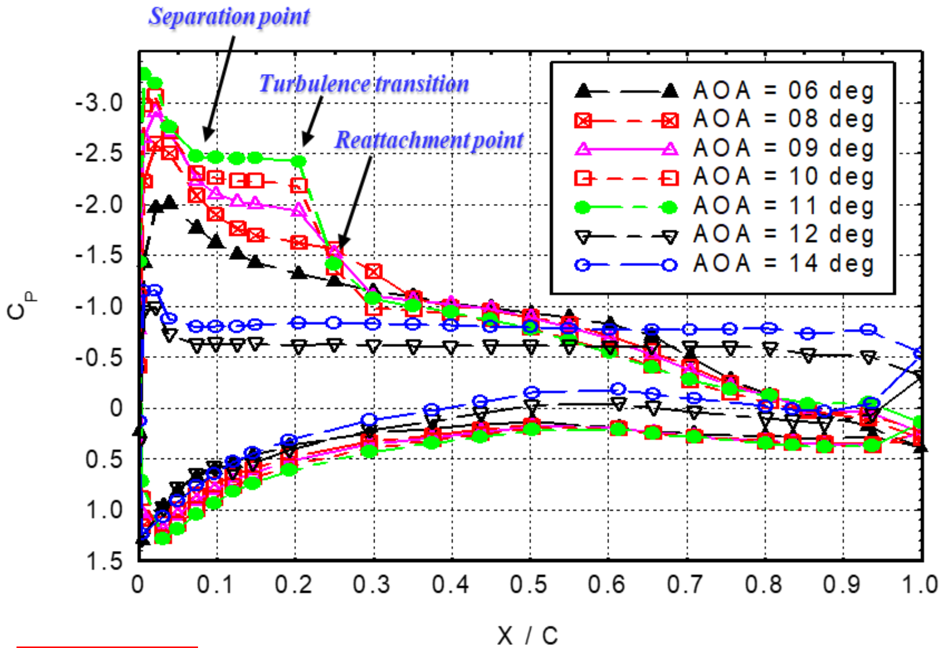


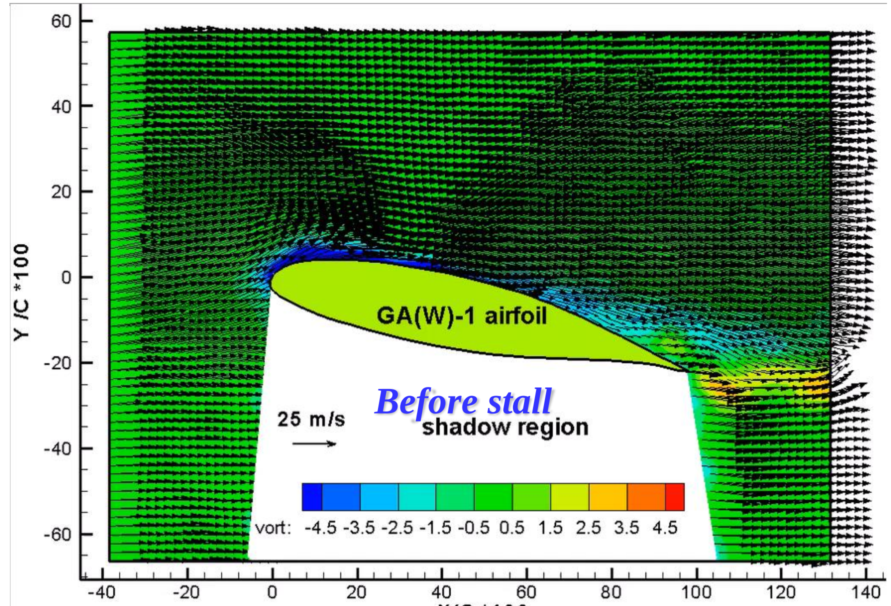
Table 1: The coordinate of the pressure taps on the DU-96-W-180 airfoil.

Lower Surface			Upper Surface		
Tap	x/c	y/c	Tap	x/c	y/c
1	0.000	0.000	22	0.920	0.018
2	0.013	-0.017	23	0.850	0.035
3	0.030	-0.025	24	0.780	0.050
4	0.040	-0.028	25	0.700	0.067
5	0.055	-0.033	26	0.620	0.083
6	0.080	-0.040	27	0.550	0.095
7	0.120	-0.048	28	0.470	0.108
8	0.145	-0.053	29	0.400	0.113
9	0.170	-0.057	30	0.320	0.113
10	0.200	-0.058	31	0.243	0.107
11	0.243	-0.062	32	0.200	0.0983
12	0.320	-0.065	33	0.170	0.092
13	0.400	-0.065	34	0.145	0.085
14	0.470	-0.060	35	0.120	0.078
15	0.550	-0.053	36	0.100	0.070
16	0.620	-0.045	37	0.080	0.062
17	0.700	-0.033	38	0.070	0.058
18	0.780	-0.022	39	0.055	0.050
19	0.850	-0.010	40	0.040	0.042
20	0.920	-0.003	41	0.030	0.035
21	1.000	0.000	42	0.013	0.022

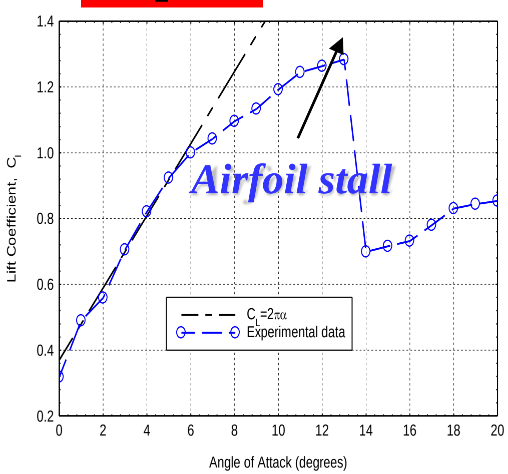
- TAP 1 is at the airfoil leading edge (LE) and TAP21 is at the airfoil trailing edge (TE)
- TAP 2~20 are along the lower surface, TAP 22~42 are along the upper surface

❑ Aerodynamic Performance of An Airfoil

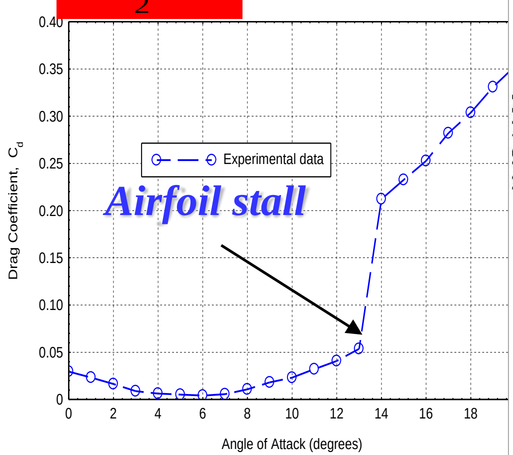


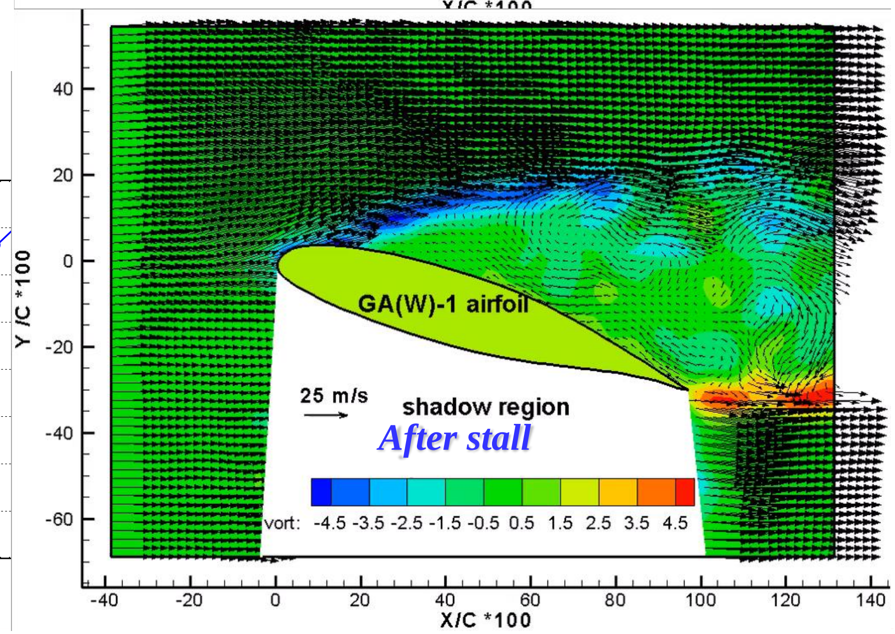


$$C_l = \frac{L}{\frac{1}{2}\rho V_\infty^2 c}$$

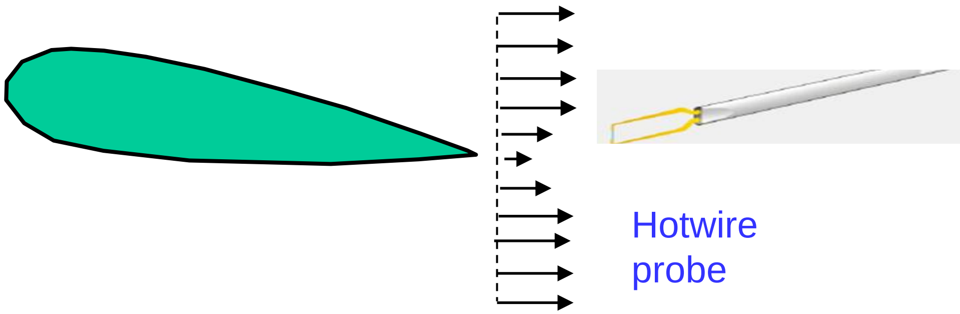


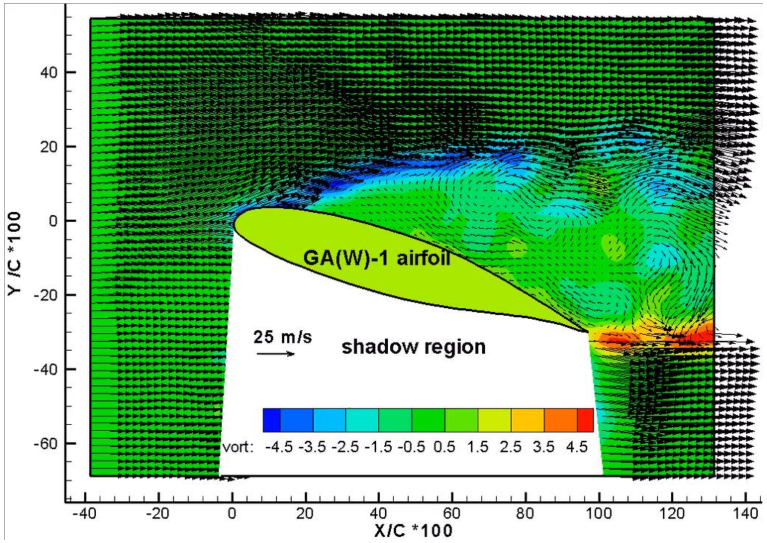
$$C_d = \frac{D}{\frac{1}{2}\rho V_\infty^2 c}$$

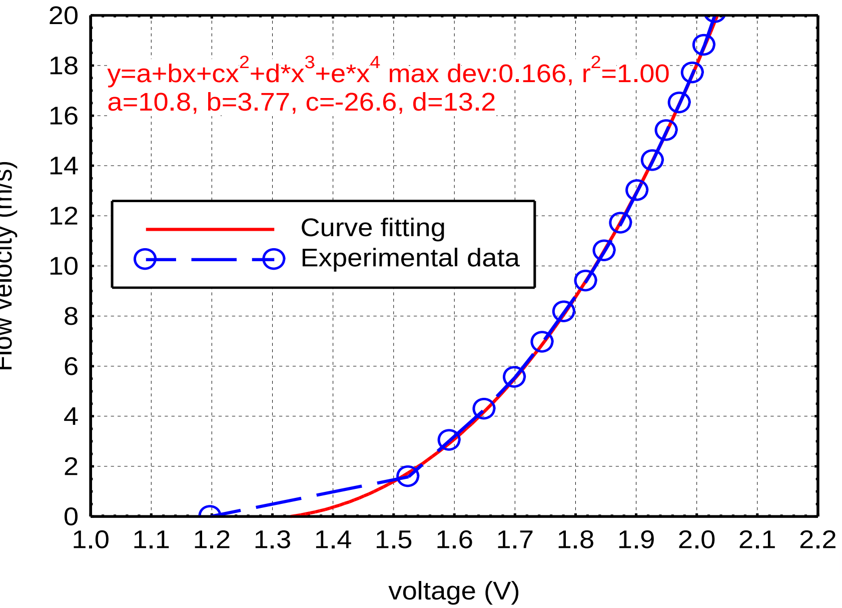


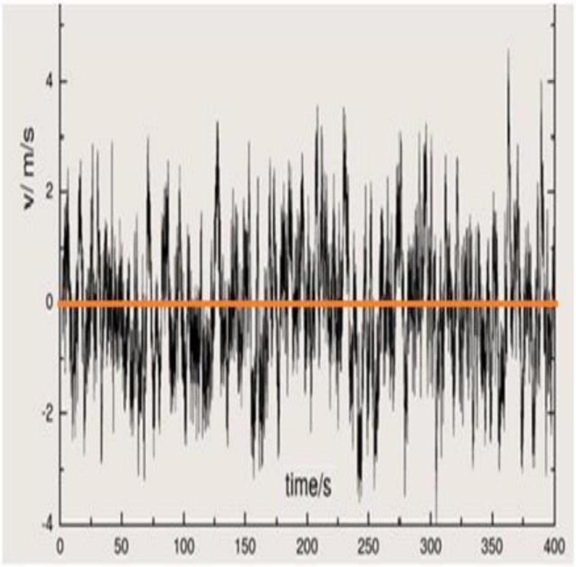


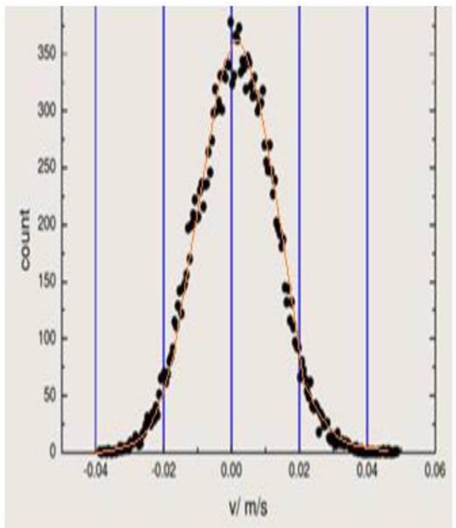
❑ Hotwire Anemometry measurements in the wake of an airfoil



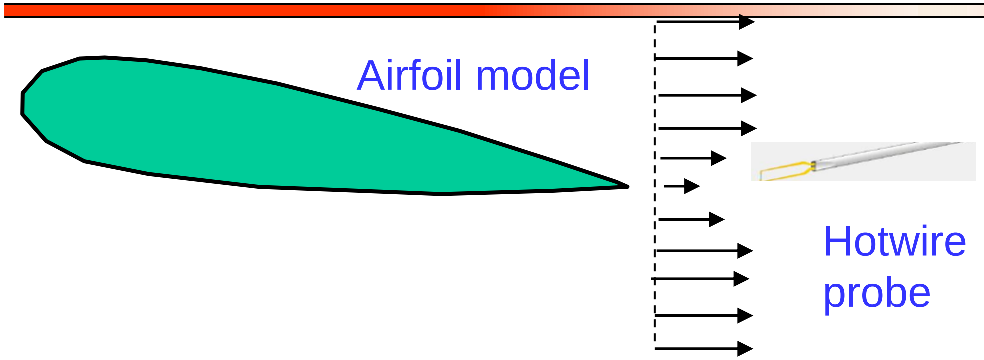


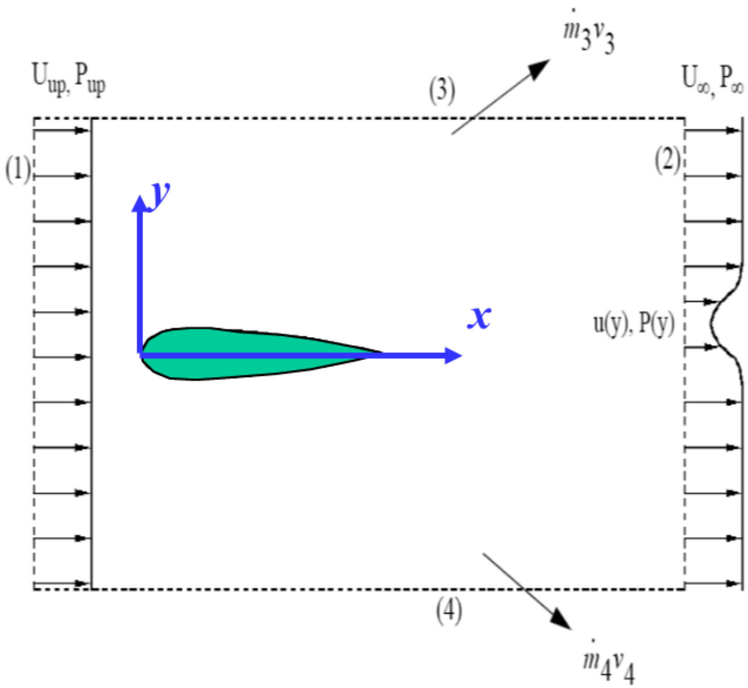






❑ Hotwire Anemometry measurements in the wake of an airfoil





Forces on CV = Fluid momentum change

Forces on CV: $\sum F_X = -D + \int_{CS} (p\hat{n}dA)_X = -D + \int_1 p_{up} dA - \int_2 p(y) dA$

Since $p_{up} = p_\infty, \quad p(y) \approx p_\infty$

$$\Rightarrow \sum F_X = -D$$

Momentum change: $\int_2 \rho U(y)\left(U(y) - U_\infty\right) dA_2 = \sum F_X = -D$

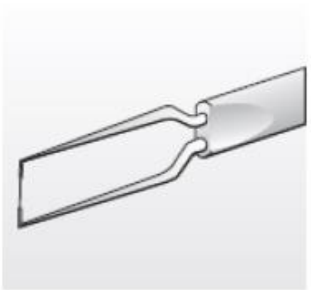
$$\Rightarrow D = \rho U^2{}_\infty \int_2 [\frac{U(y)}{U_\infty}(1 - \frac{U(y)}{U_\infty})] dA_2$$

$$C_D = \frac{D}{\frac{1}{2}\rho U_\infty{}^2 C} = \frac{\rho U^2{}_\infty \int_2 [\frac{U(y)}{U_\infty}(1 - \frac{U(y)}{U_\infty})] dA_2}{\frac{1}{2}\rho U_\infty{}^2 C}$$

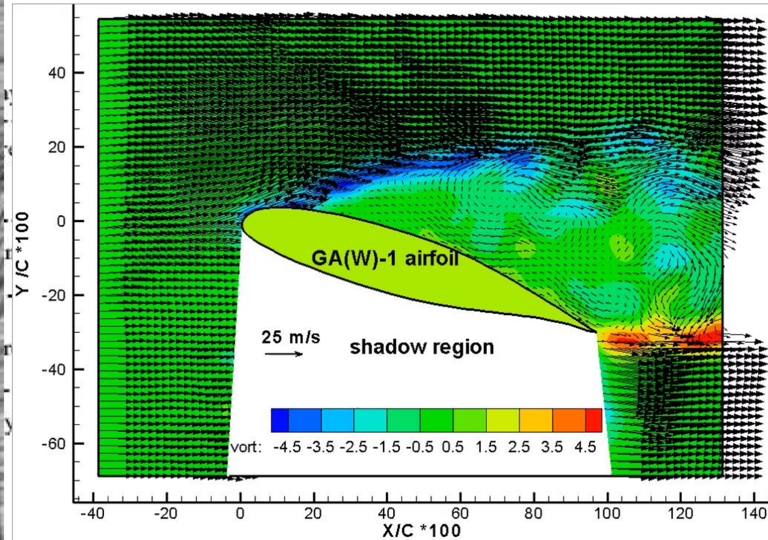
$$\Rightarrow C_D = \frac{2}{C}\int_2 [\frac{U(y)}{U_\infty}(1 - \frac{U(y)}{U_\infty})] dy$$

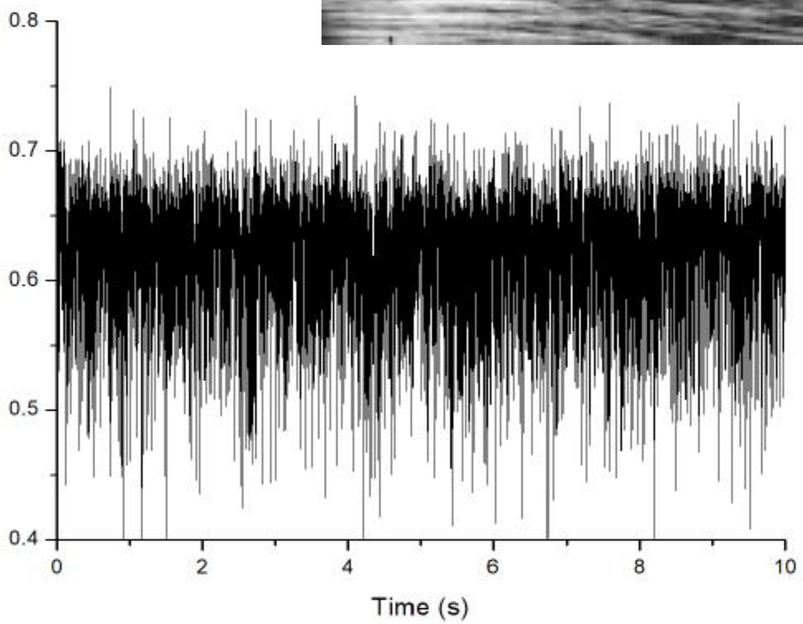
- Compare with the drag coefficients obtained based on airfoil surface pressure measurements at the same angles of attack!

❑ Hotwire Anemometry measurements in the wake of an airfoil

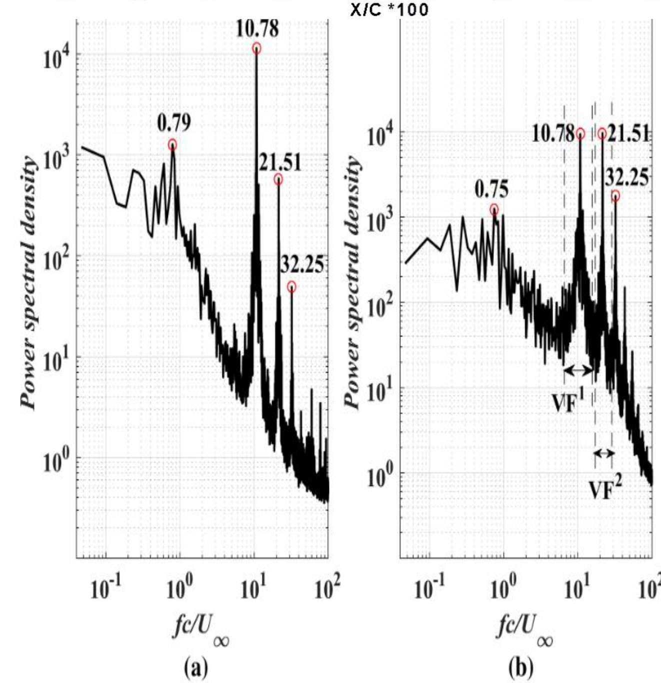


Hotwire

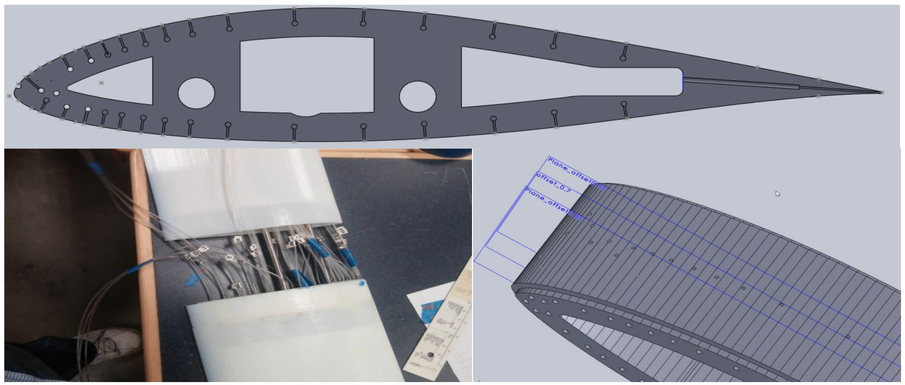


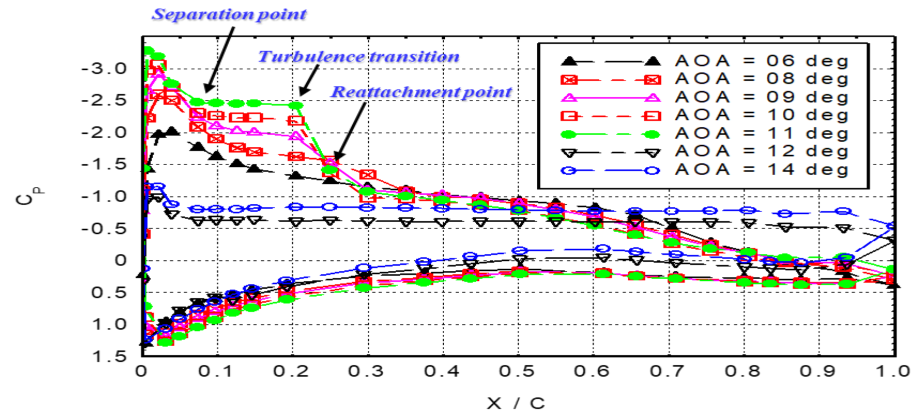


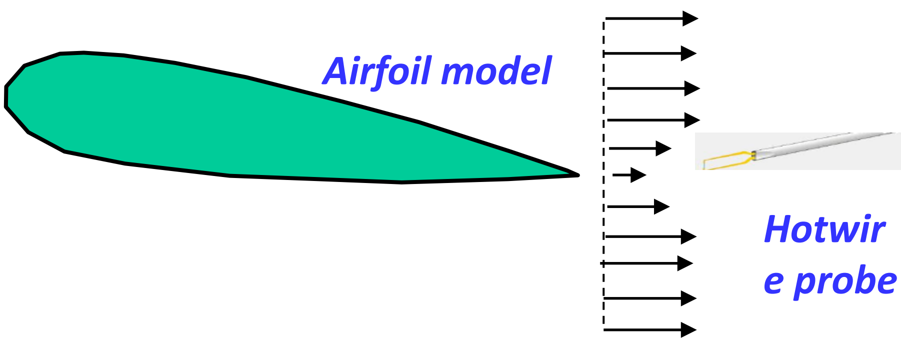
FFT

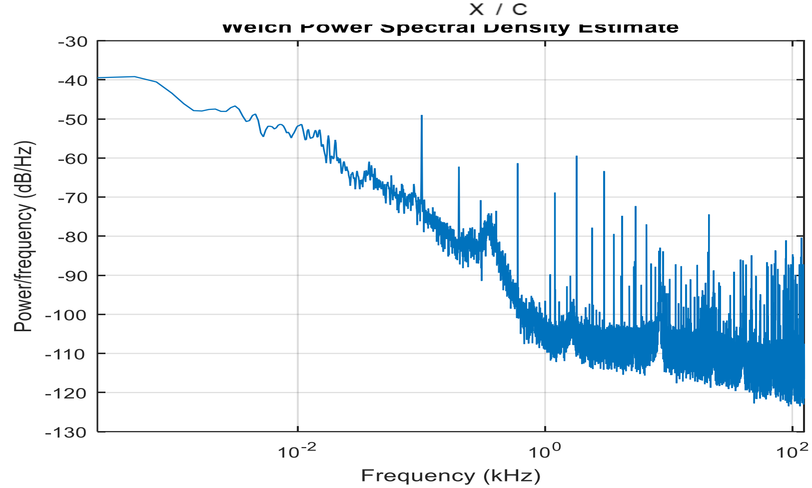


❑ Hotwire Anemometry measurements in the wake of an airfoil









- *Measured velocity spectrum based on FFT*

Required data for the lab report:

- *Wake velocity profiles at AOA =0 and 12 deg*
- *Wake turbulence intensity profiles at AOA =0 and 12 deg.*
- *Estimated drag coefficients at AOA=0, and 12 deg.*
- *FFT transformation to find vortex shedding frequency in the wake of the airfoil*
- *Discussions based on the measurement results*