Lecture # 03: Wind Tunnels and Water Tunnels

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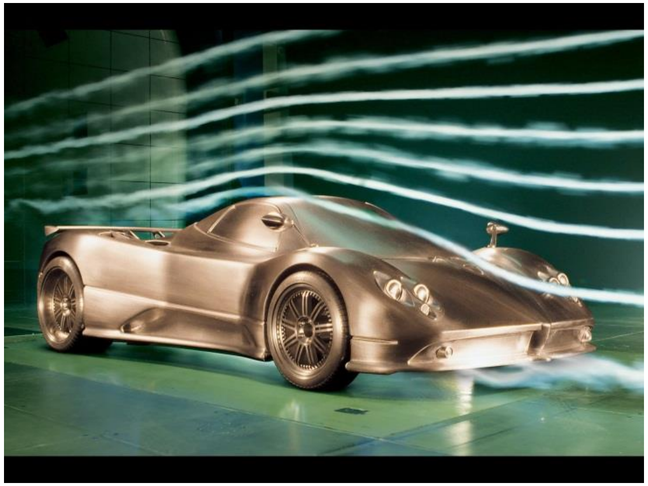
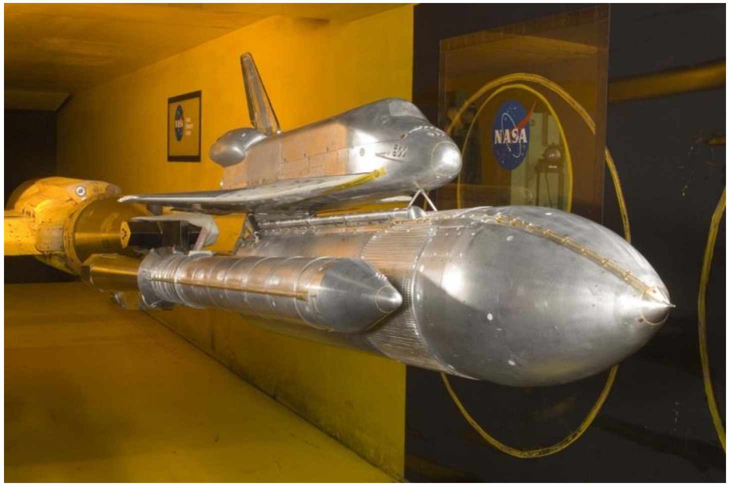
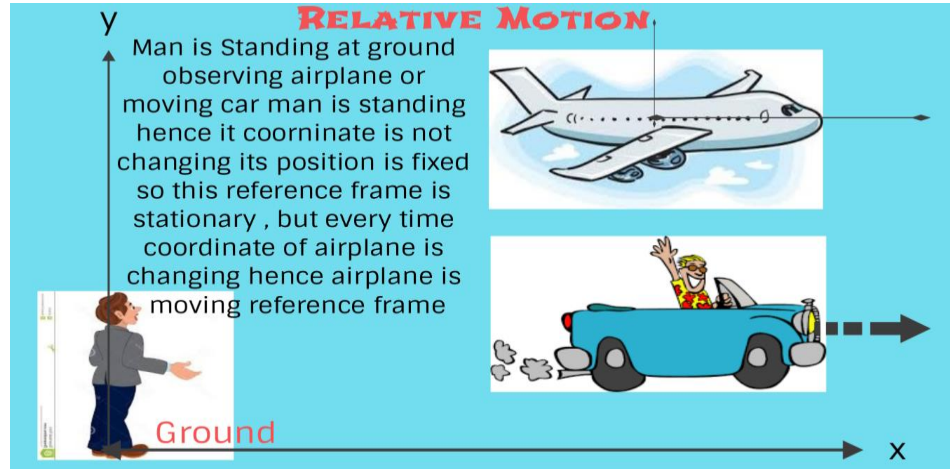
Function of Wind Tunnels and Water Tunnels

- **Producing the desired flow field with controlled conditions**

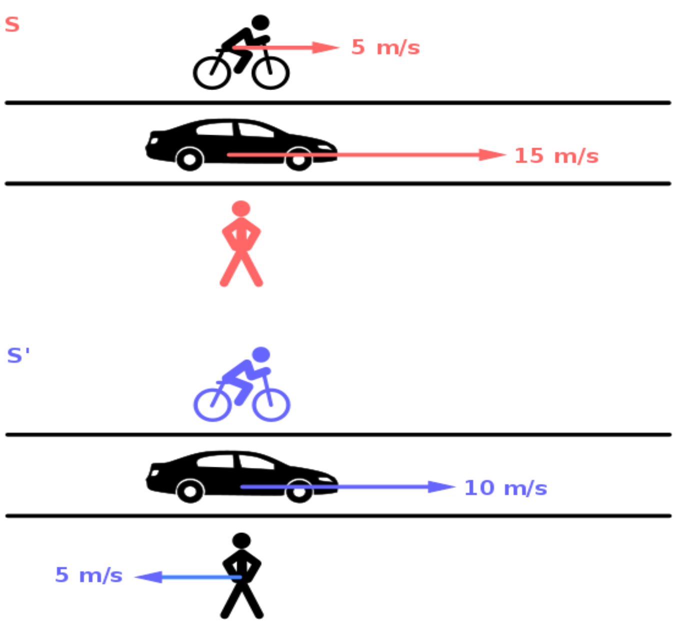


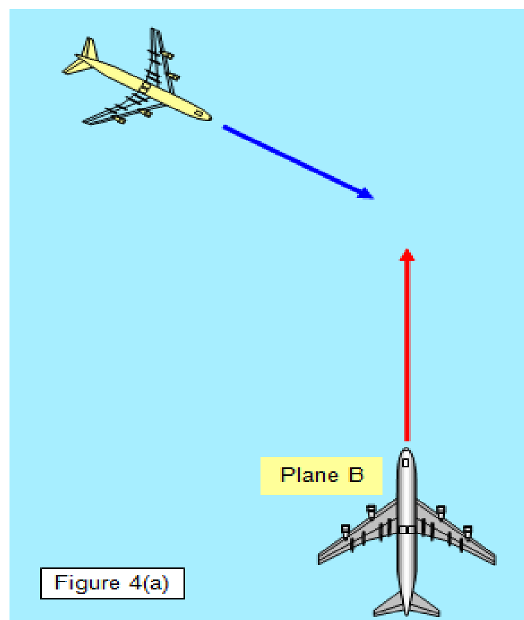


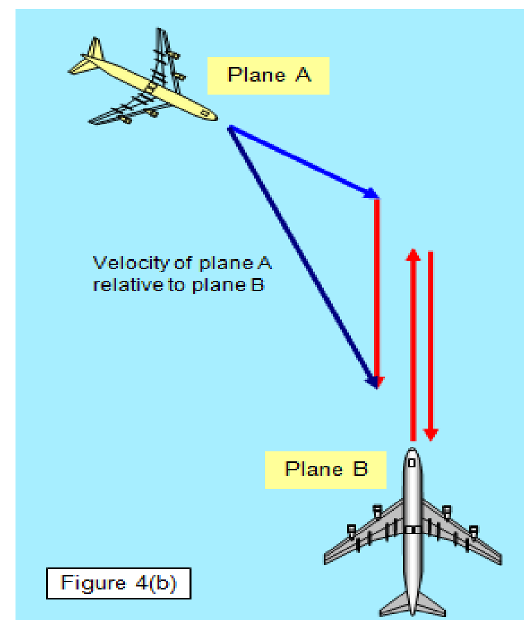
Relative Motion



- ***In classical physics and special relativity, an inertial frame of reference is a frame of reference that is not undergoing acceleration.***



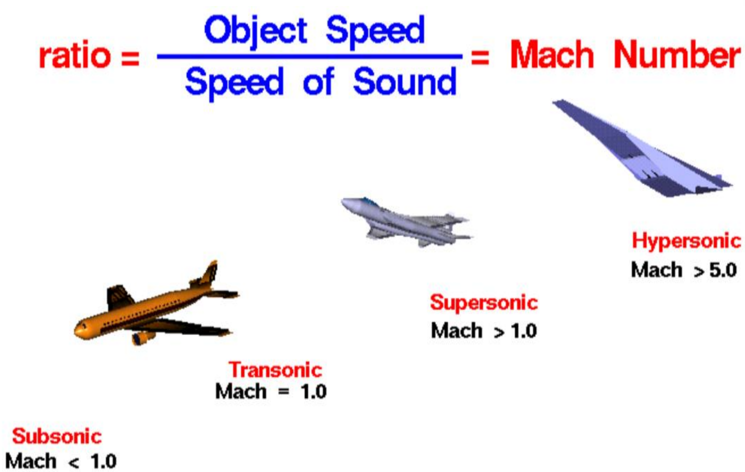


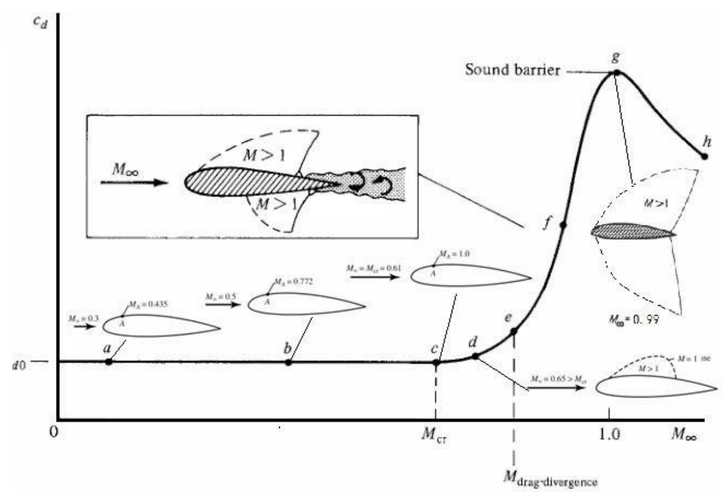


Types of Wind Tunnels

Based on Flow Speed:

- ***Subsonic or low-speed wind tunnels (M<<1.0)***
- ***Transonic wind tunnels (M≈1.0)***
- ***Supersonic wing tunnels (1.0 <M<5.0)***
- ***Hypersonic wind tunnels (M>5.0)***



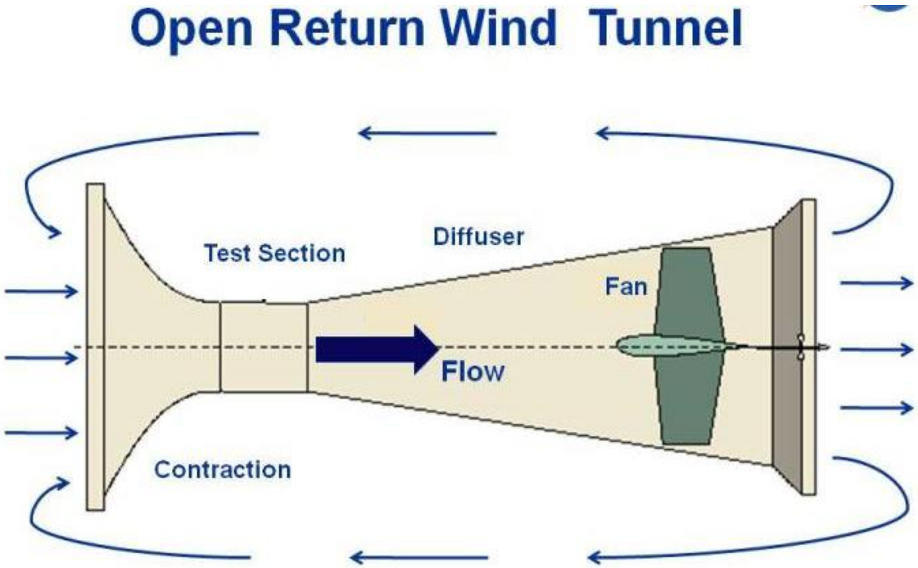


Sketch of the variation of profile drag coefficient with freestream Mach number, illustrating the critical and drag-divergence Mach numbers and showing the large drag rise near Mach 1.

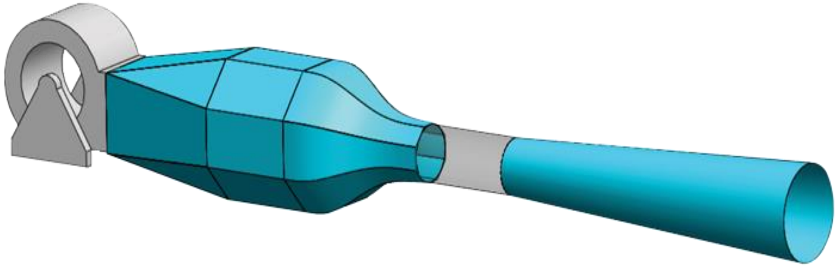
Types of Wind Tunnels

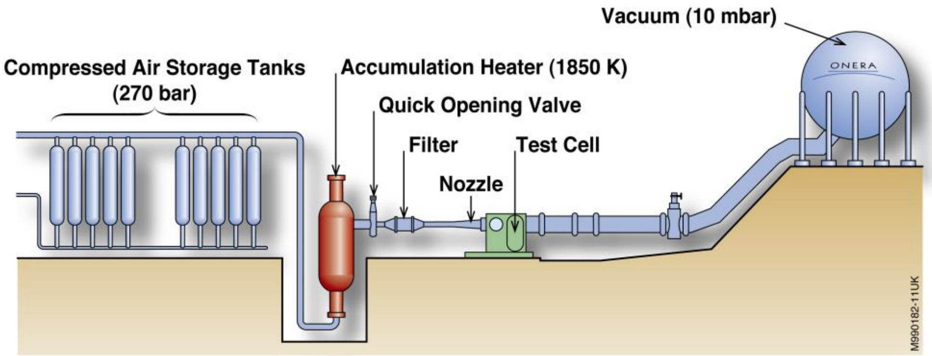
Based on Shape:

- ***Open circuit wind tunnel:***



- ***Suction wind tunnel:*** ***With the inlet open to atmosphere, axial fan or centrifugal blower is installed after test section.***



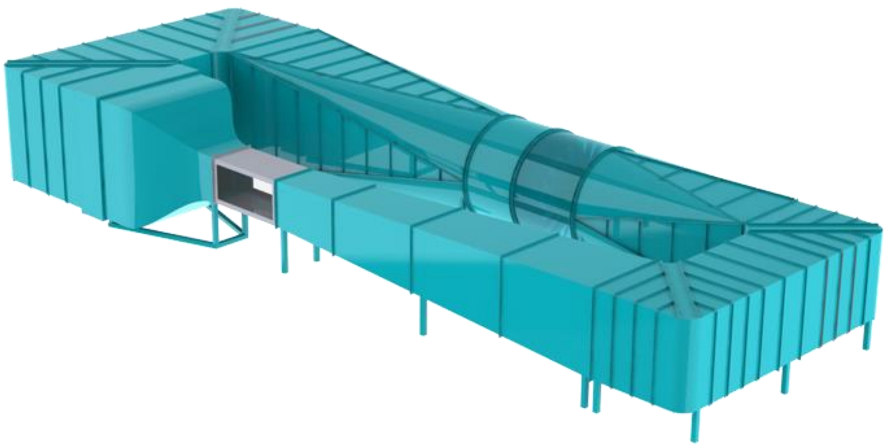


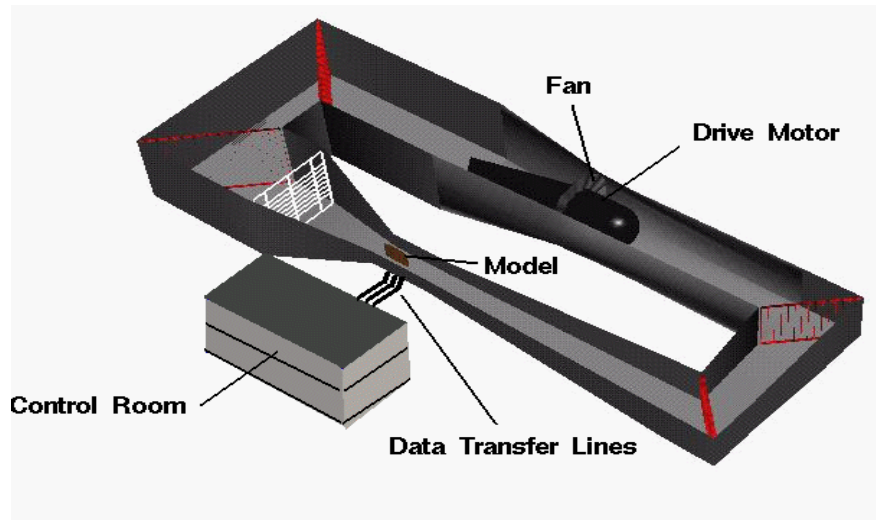
- ***Blow down wind tunnel:*** ***A blower is installed at the inlet of wind tunnel which throws the air into wind tunnel.***

Types of Wind Tunnels

Based on Shape:

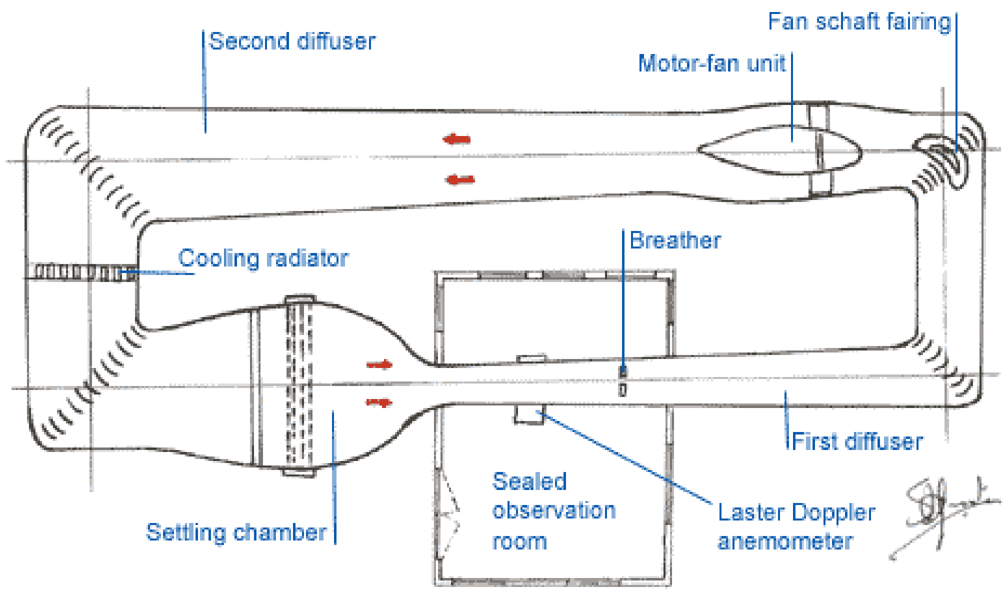
- ***Close-circuit wind tunnel:***



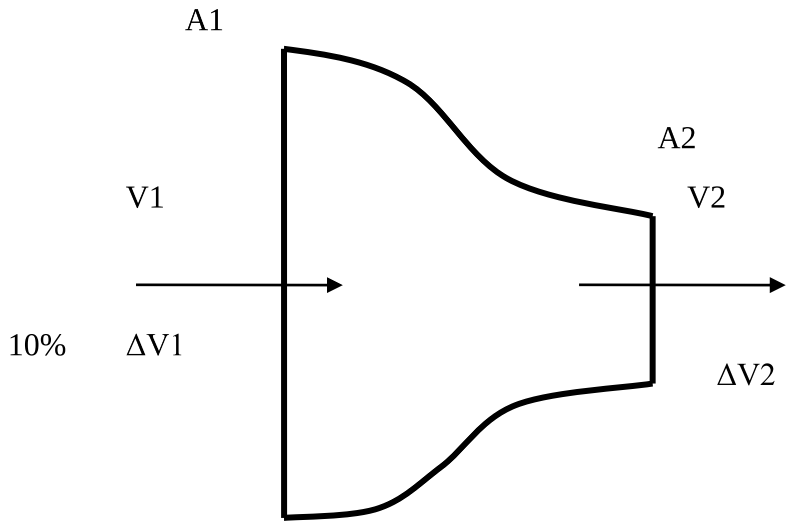


Components of a Closed-Looped Wind Tunnel

- *Test section*
- *Contraction section*
- *Diffuser section*
- *Setting chamber*
- *Screens and similar structures*
- *Cooling system / radiators*
- *Motors /fans*



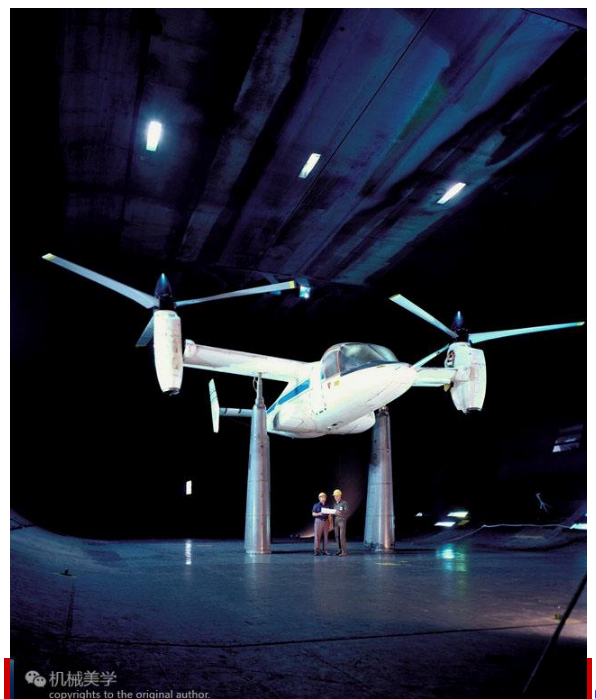
Function of Contraction

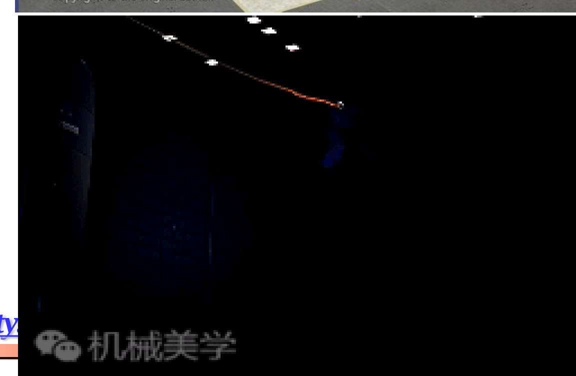


$$c_1 = \frac{A_1}{A_2} \qquad if \quad \frac{\Delta V_1}{V_1} = 0.1 \qquad \frac{\Delta V_2}{V_2} = \frac{1}{c^2}\frac{\Delta V_1}{V_1} = \frac{0.1}{100} = 0.001$$

NASA Ames Wind Tunnel
(24.4m × 36.6m test section, 75GW power)

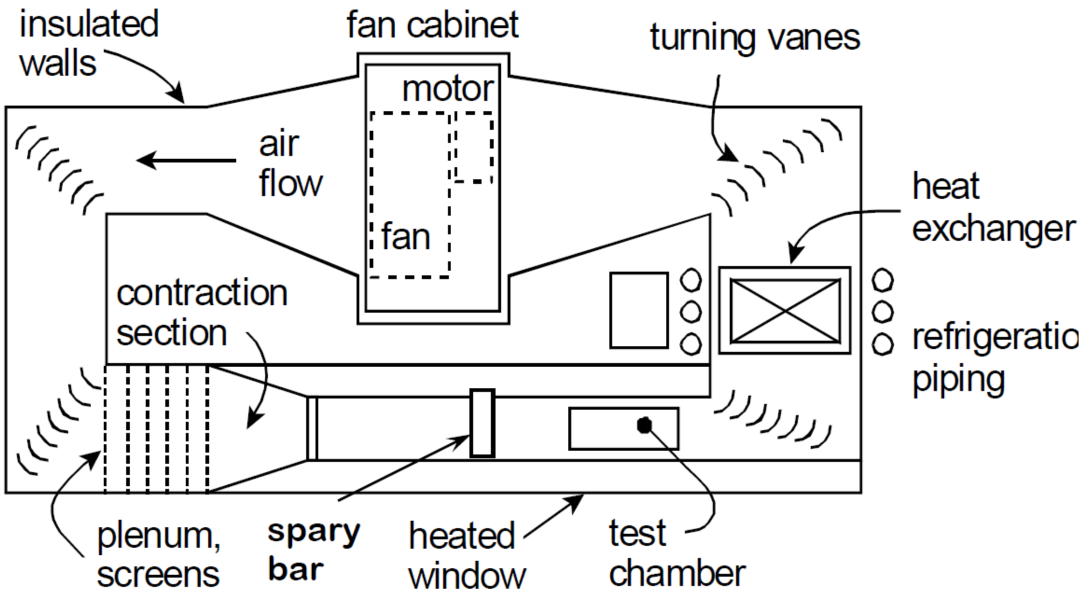




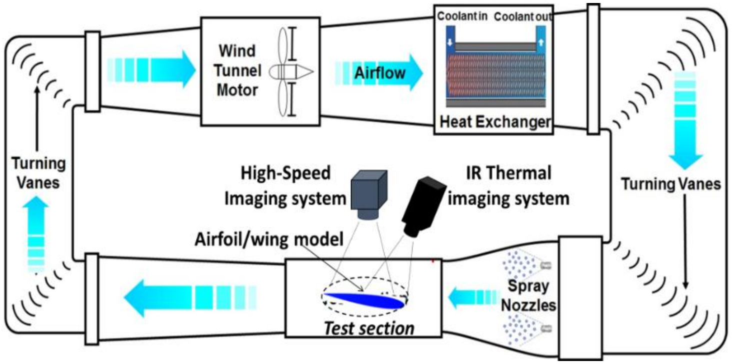
NASA Ames Wind Tunnel
(24.4m × 36.6m test section, 75GW power)

Icing Wind Tunnels

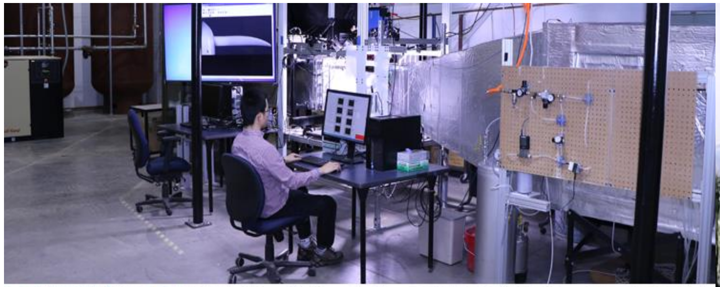


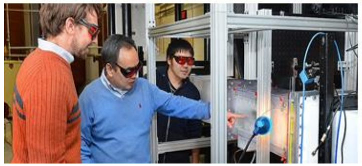
Icing Tunnel at NASA Glenn Center

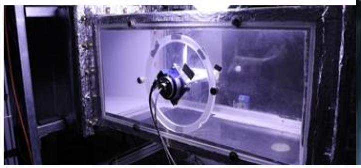
❑ Icing Research Tunnel @ Iowa State University (ISU-IRT)



- ISU Icing Research Tunnel (ISU-IRT), donated by Collins Aerospace System, is a new refurbished, research-grade multi-functional icing research tunnel.
- The working parameters of the ISU-IRT include:
  - Test section: 0.4m × 0.4m×2.0m
  - Airflow velocity: $V_{\infty} = 5 \sim 100$ m/s;
  - Temperature: $T_{\infty} = -25\ ^{\circ}C \sim 20\ ^{\circ}C$;
  - Droplet size: $D_{droplet} = 10 \sim 100\ \mu m$;
  - Liquid Water Content: $LWC = 0.1 \sim 10\ g/m^3$
- The large LWC range allows ISU-IRT to be run over a wide range of conditions (i.e., from dry rime to wet glaze icing).
- We received ~$4.0M in funded research in the past 5 years from NASA, NSF, FAA, NAVY, GE, P&W, UTAS, DuPont…

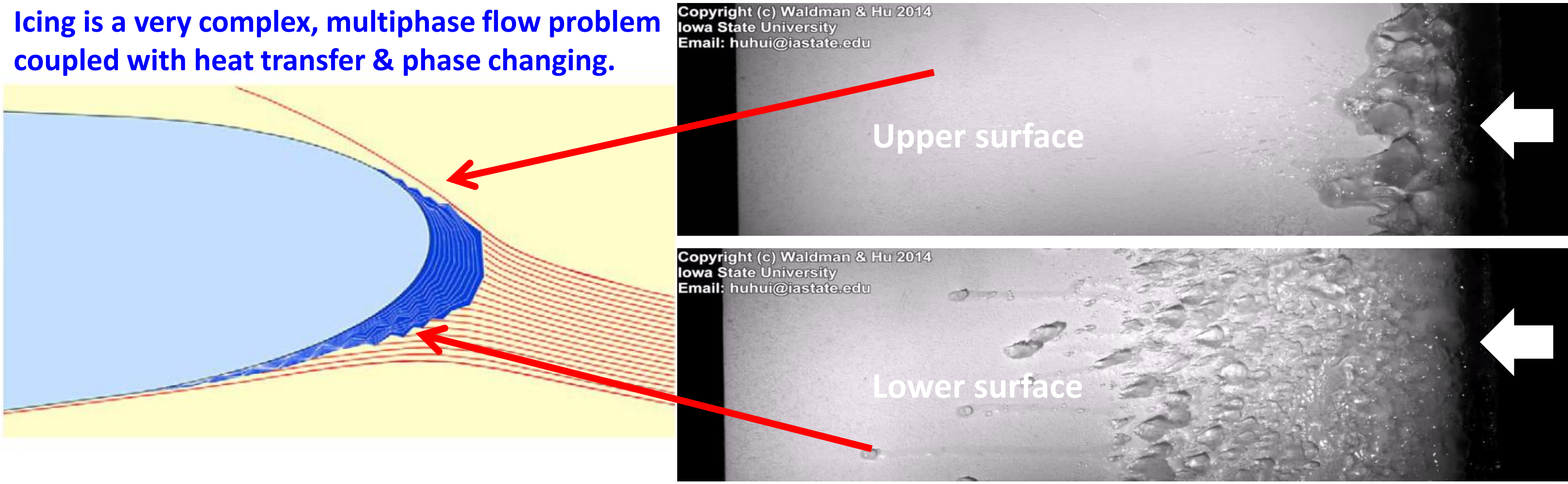


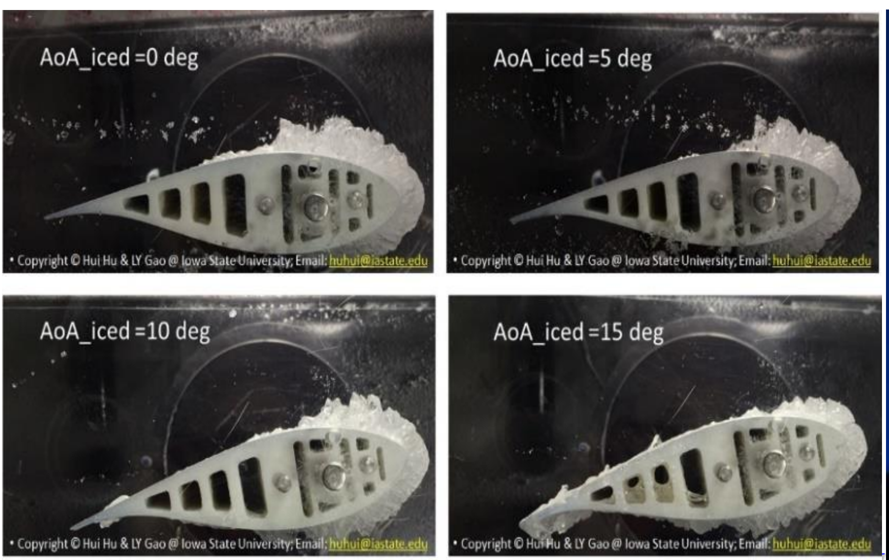


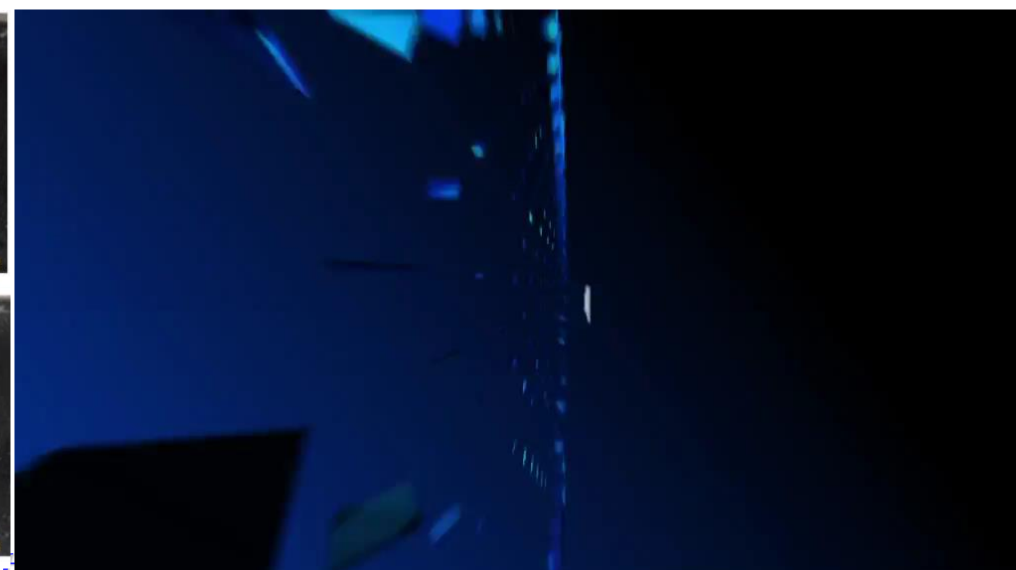


❑ Icing Research Tunnel @ Iowa State University (ISU-IRT)

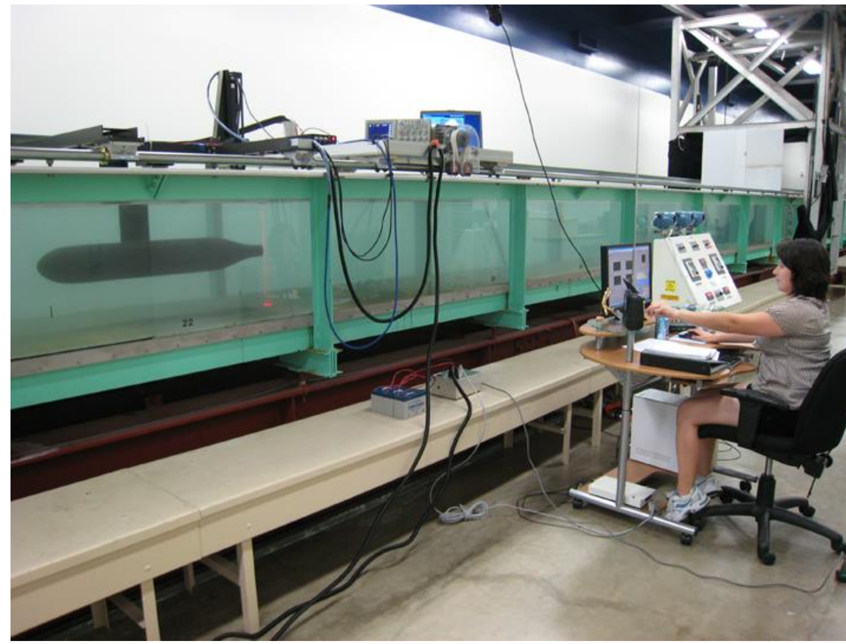
- Icing is a very complex, multiphase flow problem coupled with heat transfer & phase changing.





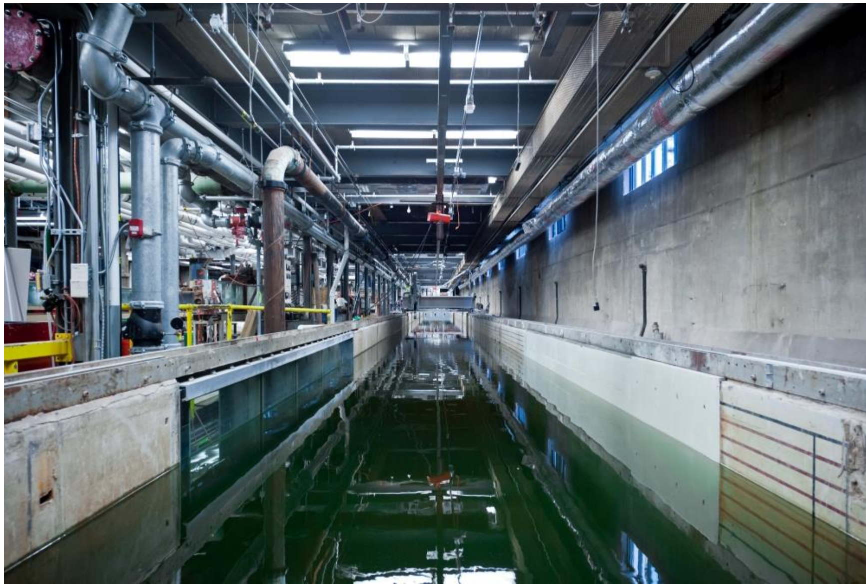


Water Tunnels



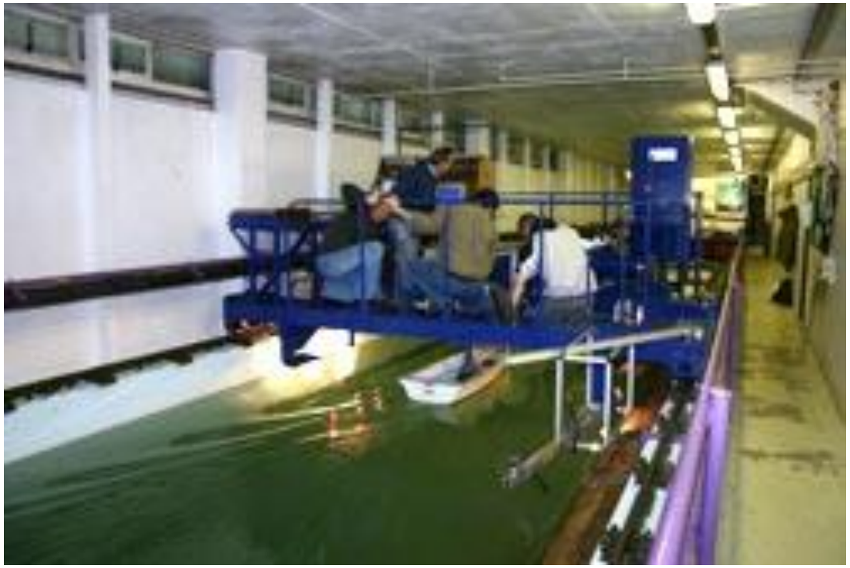
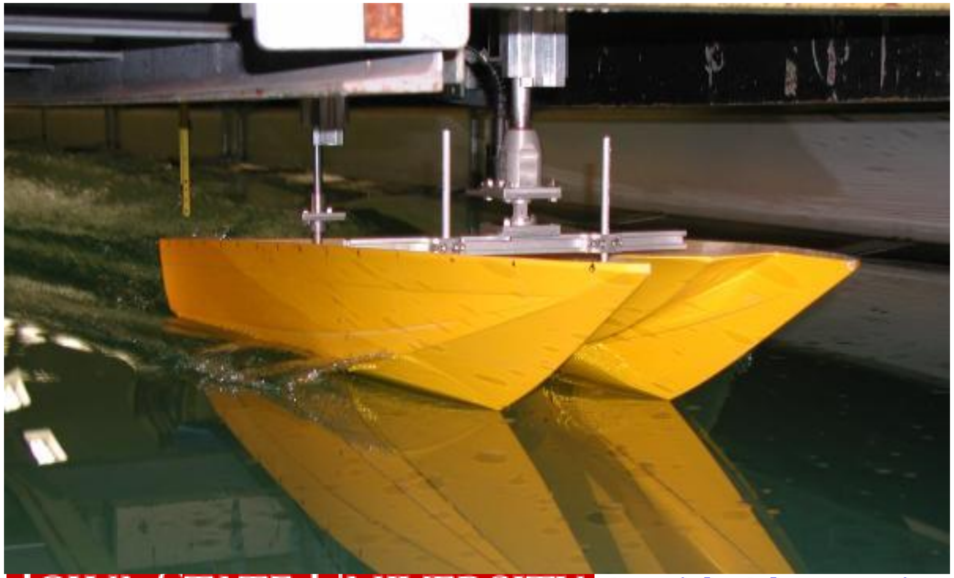
Water Tunnels

- *Saint Anthony Falls Laboratory; University of Minnesota*

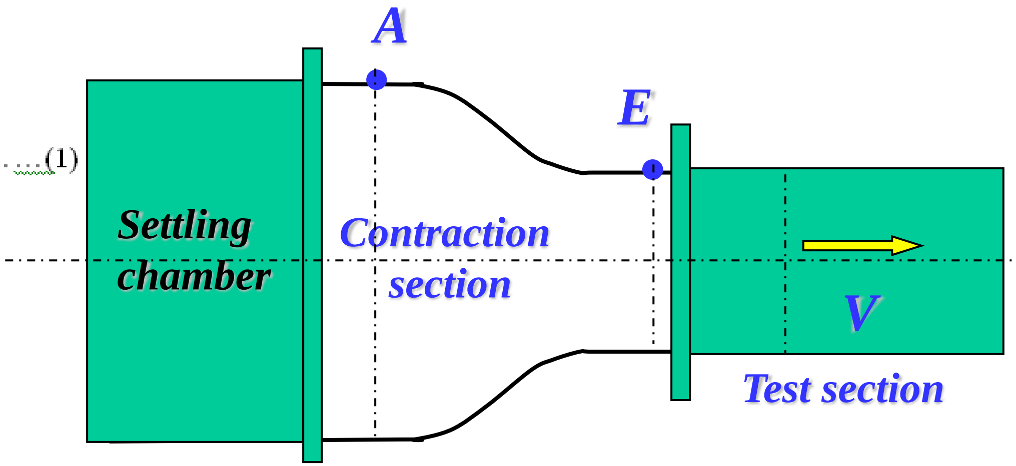


- *Hydro science research laboratory at the University of Iowa*

Towing Tank


Lab#02: Wind Tunnel Calibration



$P_{0A} \neq P_{oE}$ in fact $P_{0A} > P_{oE}$

Where $P_{0A} = p_A + q_A = p_E + q_E + (P_{0A} - P_{0E})$ ....(1)

Define a total pressure loss coefficient by the relation

$$C_1 = \frac{P_{0A} - P_{0E}}{q_E}$$

Equation (1) can now be written as

$$p_A - p_E = q_E + C_1 q_E - q_A \text{...(2)}$$

If A_A, A_E and A_T are the areas of the different sections, then the conservation of mass principle can be written to relate the mass flow rates between the between the different sections as:

$$\rho_A V_A A_A = \rho_E V_E A_E = \rho_T V_T A_T$$

Low speed flows can be treated as inviscid flows, i.e., $\rho_A = \rho_E = \rho_T$. The fluid density can be cancelled from the above relation, therefore,

$$V_A A_A = V_E A_E = V_T A_T.$$

Squaring the above equation, and multiplying through by $\rho/2$ yields

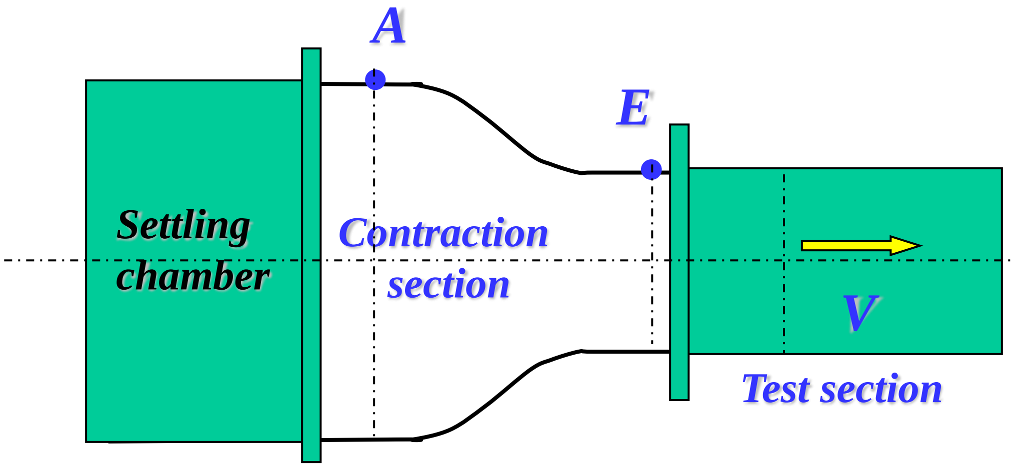
$$\frac{1}{2}\rho_A V_A{}^2 A_A{}^2 = \frac{1}{2}\rho_E V_E{}^2 A_E{}^2 = \frac{1}{2}\rho_T V_T{}^2 A_T{}^2.$$

Lab#02: Wind Tunnel Calibration

Letting $q_A = \frac{1}{2}\rho_A V_A^2$, $q_E = \frac{1}{2}\rho_E V_E^2$ and $q_T = \frac{1}{2}\rho_T V_T^2$ result in

$$q_A A_A^2 = q_E A_E^2 = q_T A_T^2 .$$

From which $q_A = q_E \frac{A_E^2}{A_A^2}$ and $q_E = q_T \frac{A_T^2}{A_E^2}$



Define:

$$C_2 = \frac{A_E^2}{A_A^2} \quad \text{and} \quad C_3 = \frac{A_T^2}{A_E^2}$$

Hence :

$$q_A = C_2\, q_E \quad \text{..(3)}$$

$$q_E = C_3\, q_T \quad \text{..(4)}$$

Using (3) and (4) into equation 2 yields :

$$p_A - p_E = C_3 q_T + C_1\, C_3 q_T - C_2 C_3 q_T = (1 + C_1 - C_2)\, C_3 q_T \qquad (5)$$

Note: No assumptions have been made between E and T, i.e., $P_{0E} = P_{0T}$. Now, if $A_E = A_T$ then

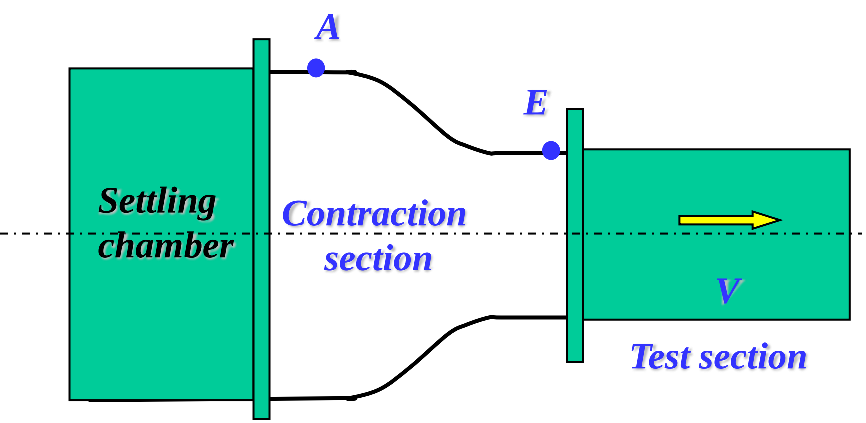
$C_3 = \frac{A_T^2}{A_E^2} = 1$, and equation (5)reduces to $p_A - p_E = \Delta p = (1 + C_1 - C_2)\, q_T$ or $\Delta p = C\, q_T$,

$$p_A - p_E = \Delta p = C * q_T = C * \frac{1}{2}\rho V^2$$

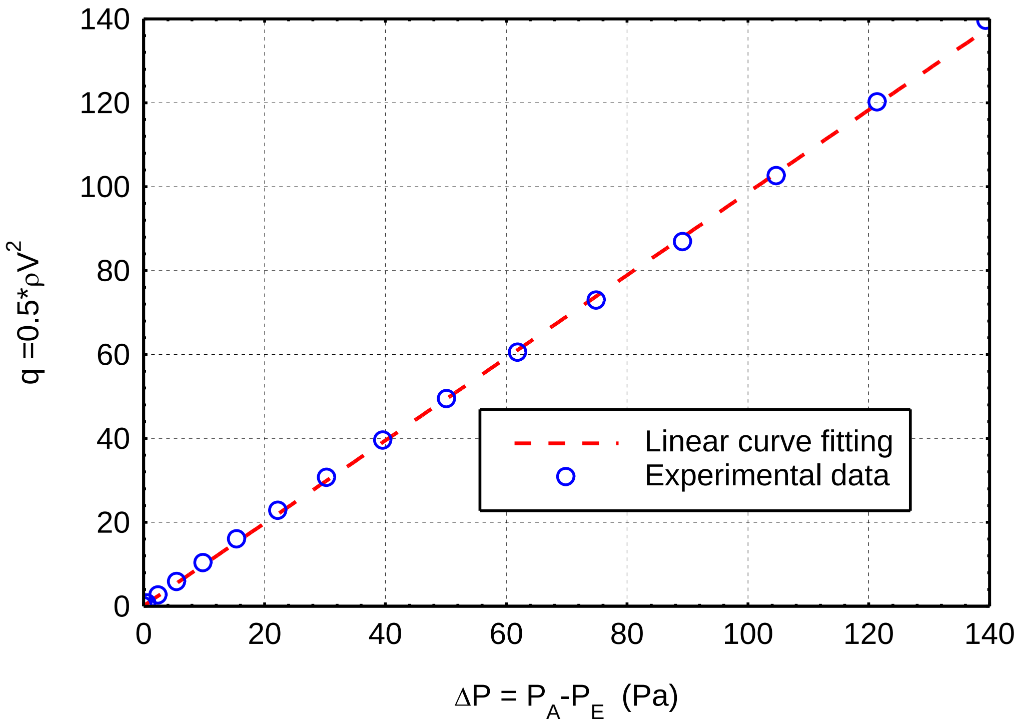
where C is determined by calibration. C_2 is determined by measuring areas. C_1 is calculated from $C_1 = C + C_2 - 1$.

$K = 1/C = q_T / \Delta p$ is defined as the wind tunnel calibration constant.

Lab#02: Wind Tunnel Calibration



$$p_A - p_E = \Delta p = C * q_T = C * \frac{1}{2}\rho V^2$$



Before you do the Labs...

- *Choose 1~2 member as the Lead Operators*
- *Bring you own flash drive for the data storage.*
- *Do not touch other research equipment's in the wind tunnel laboratory.*
- *Keep the wind tunnel laboratory clean and organized.*