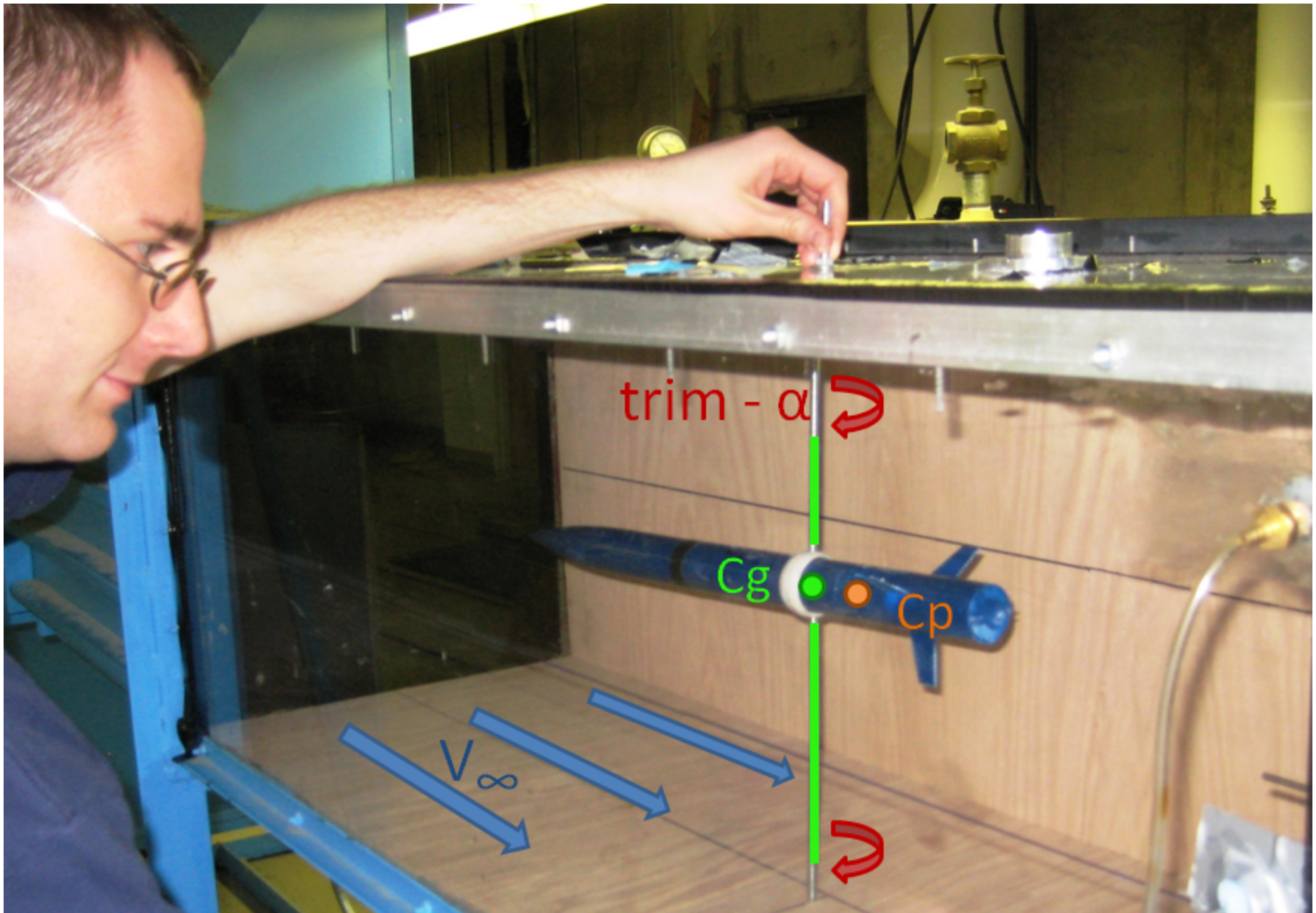
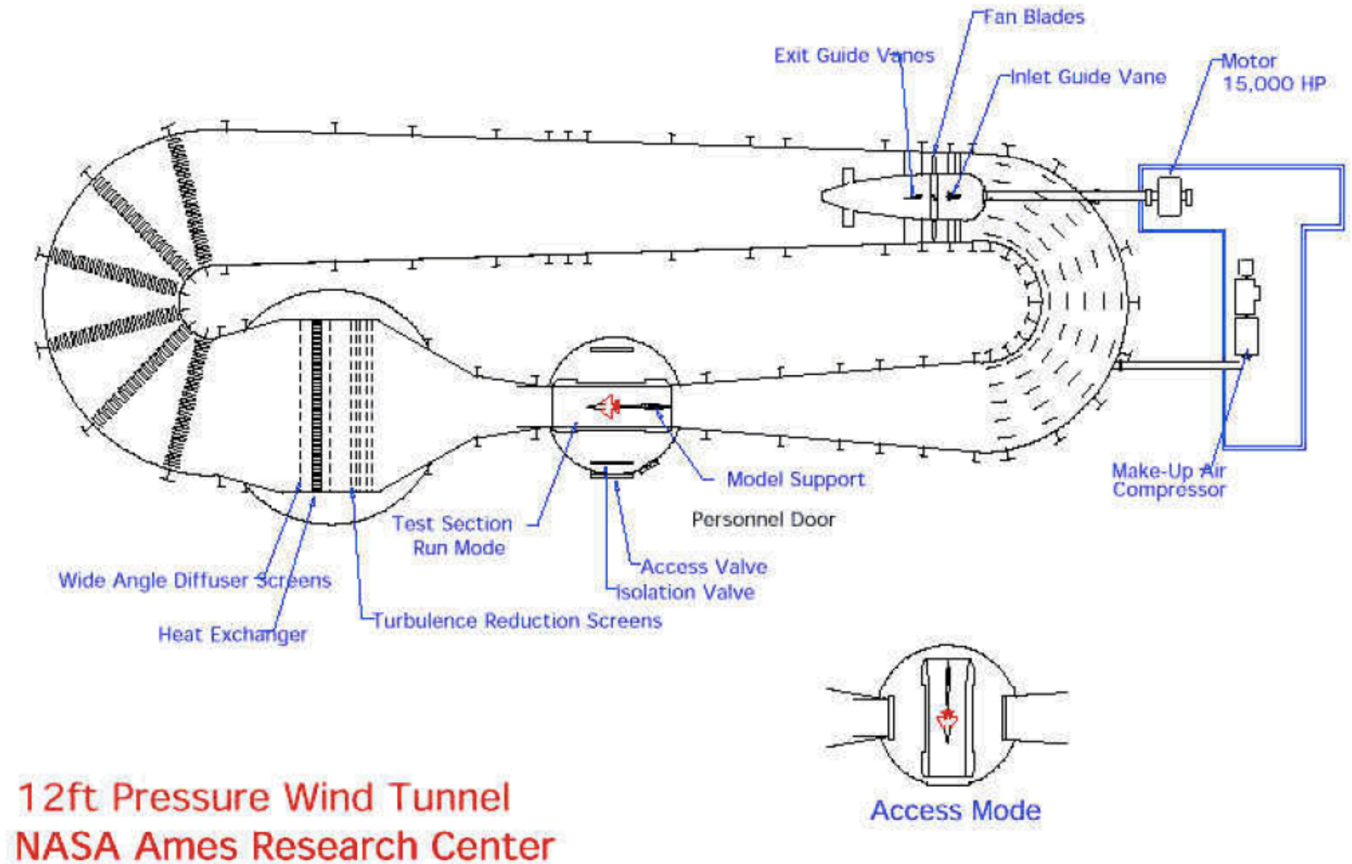
Wind Tunnel Testing: Setup and Procedures



Wind Tunnel Types

Closed Circuit Tunnel

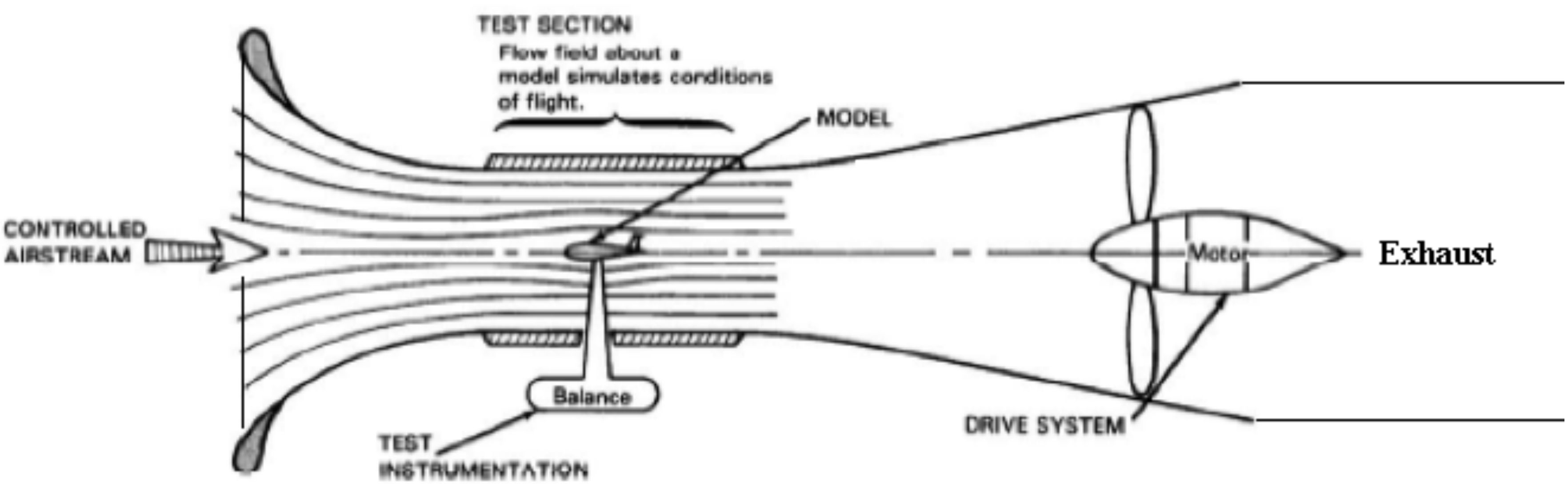
$$\left(P_0\right)_{tunnel} \geq p_{ambient}$$



Wind Tunnel Types (2)

Our Tunnel is an “Open Circuit” Tunnel

$\left(P_0 \right) \leq p$



About Wind Tunnel Testing

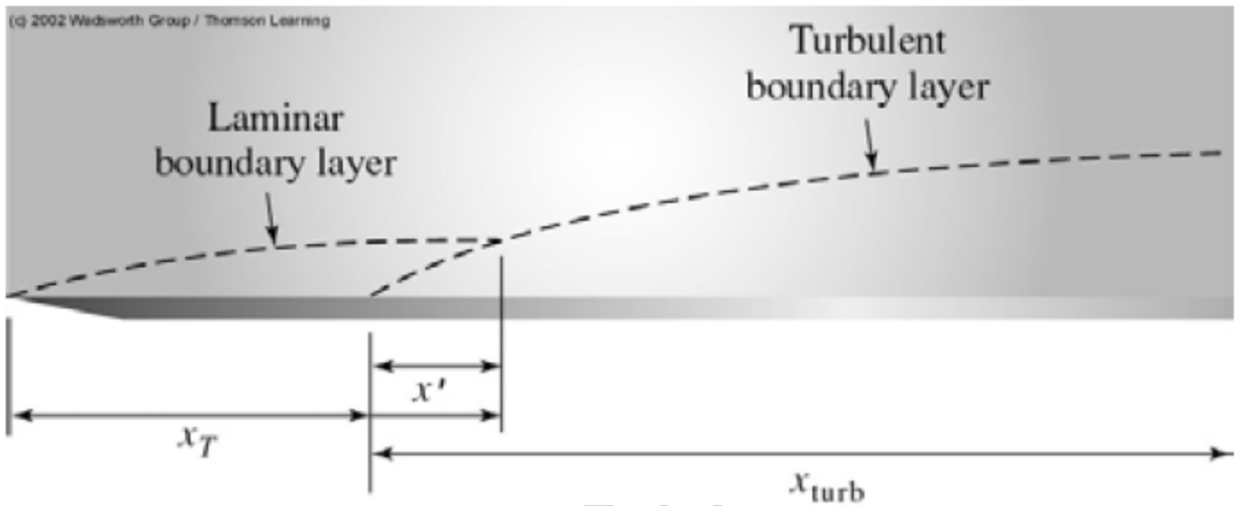
Key issues

- Maintaining Reynolds number \, Mach number similarity
- Accounting for possible flow non-uniformities in the wind tunnel
- Wind Tunnel Blockage
- Effects of the model support system.
- Leaks and Losses
- Open or Closed Circuit Tunnel

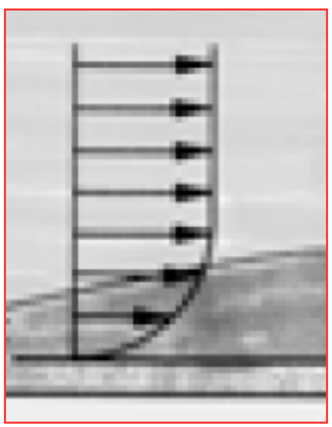
Turbulent or Laminar Flow?

- In most cases the *full scale flight conditions* will produce *turbulent flow*.
- In wind tunnels, low Reynolds number will result in a significant amount o*f laminar flow.*
- To achieve a boundary layer similar flight Reynolds number, the boundary layer is often "tripped" to force *transition to turbulent flow.*

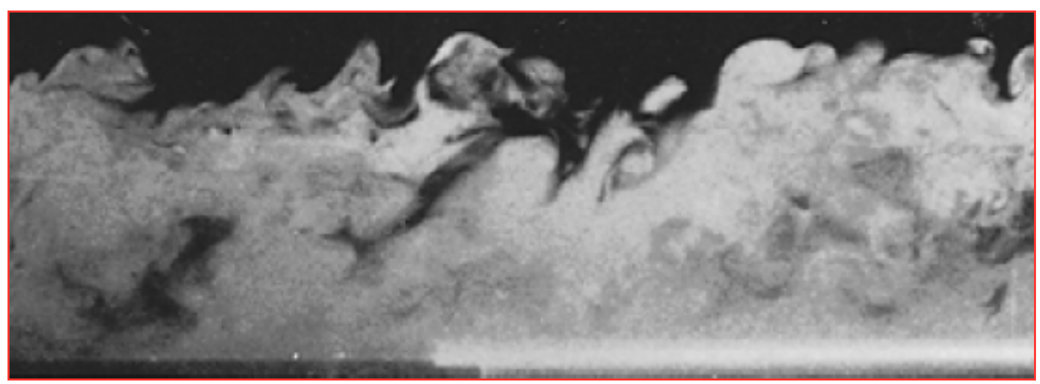
Laminar and Turbulent Boundary Layers



- Laminar

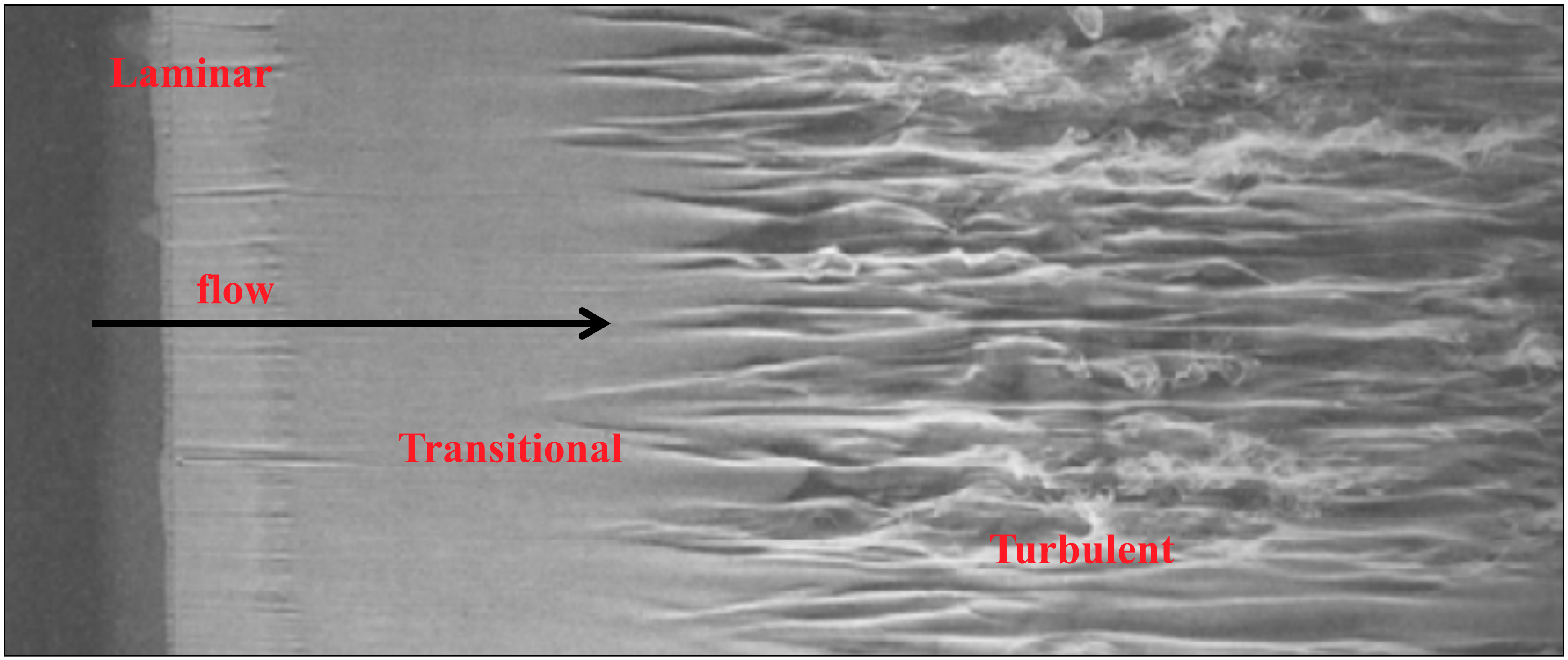


- Turbulent



Laminar and Turbulent Boundary Layers (2)

- Location of transition point strongly a function of ***Reynolds number***



- Laminar --> orderly
- Turbulent --> chaotic

Comparison of Reynolds Number and Mach Number

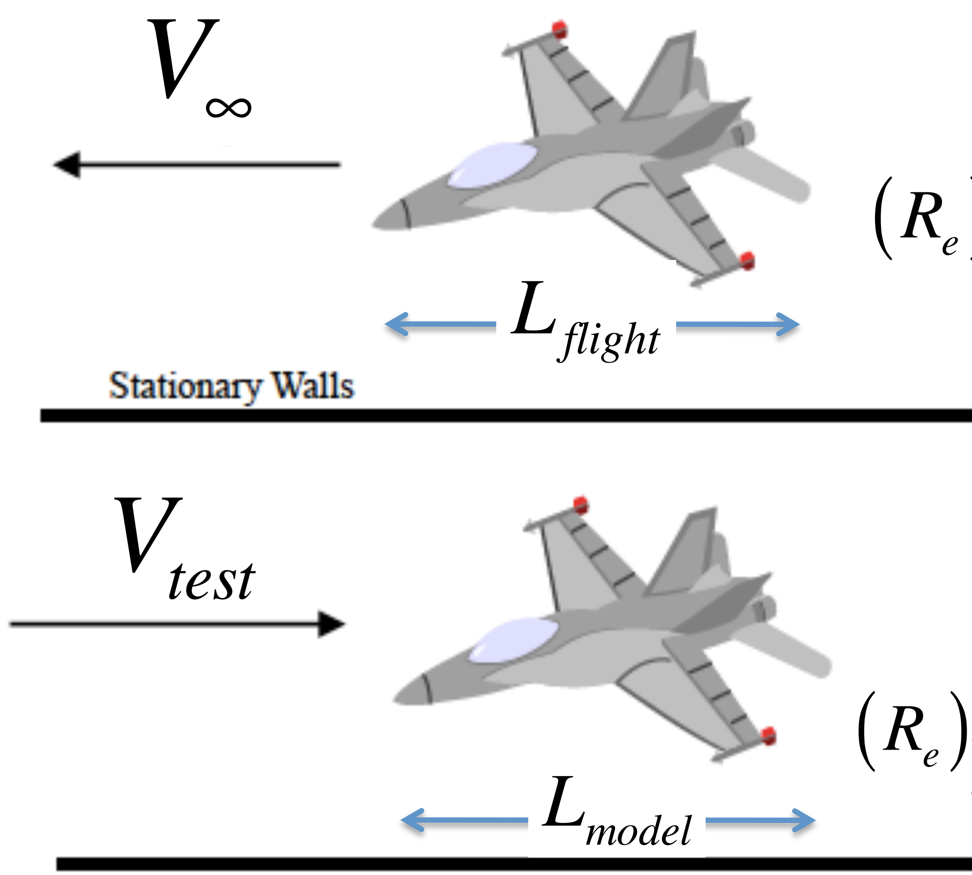
Mach number is a measure of the ratio of the fluid Kinetic energy to the fluid internal energy (direct motion To random thermal motion of gas molecules)
-- Fundamental Parameter of Compressible Flow --

$$M = \frac{V}{c} = \sqrt{\left(\frac{2}{\gamma \cdot (\gamma - 1)}\right) \cdot \frac{\left(\frac{V^2}{2}\right)}{e}}$$

Reynold's number is a measure of the ratio of the Inertial Forces acting on the fluid -- to -- the Viscous Forces Acting on the fluid
-- Fundamental Parameter of Viscous Flow --

$$R_e = \frac{\rho V L}{\mu} = 2\frac{L}{\delta} \cdot \frac{\rho V^2}{\tau_{wall}} \approx \frac{Inertial - Forces}{Viscous - Forces}$$

About Wind Tunnel Testing (2)



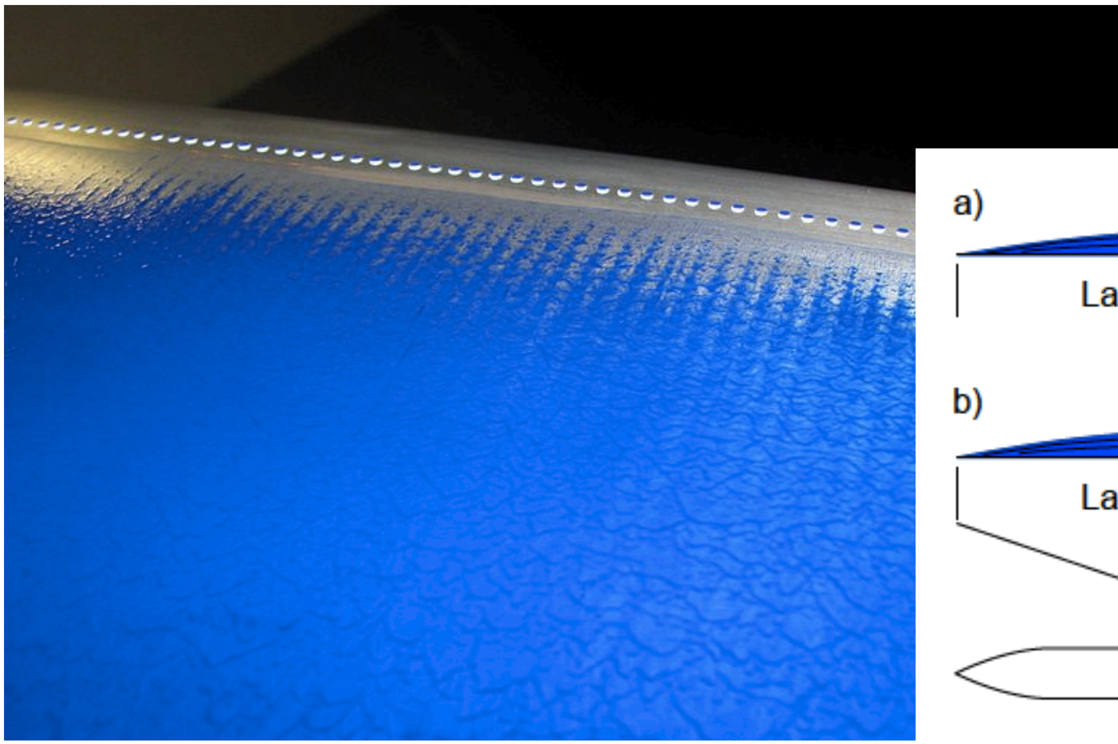
$$\left(R_e\right)_{flight} = \frac{\rho_\infty \cdot V_\infty \cdot L_{flight}}{\mu_\infty}$$

$$\left(R_e\right)_{flight} \neq \left(R_e\right)_{\substack{wind \\ tunnel}}$$

$$\left(R_e\right)_{\substack{wind \\ tunnel}} = \frac{\rho_{test} \cdot V_{test} \cdot L_{model}}{\mu_{test}}$$

About Wind Tunnel Testing (3)

Trip Strip along leading edge of a wind tunnel model airfoil



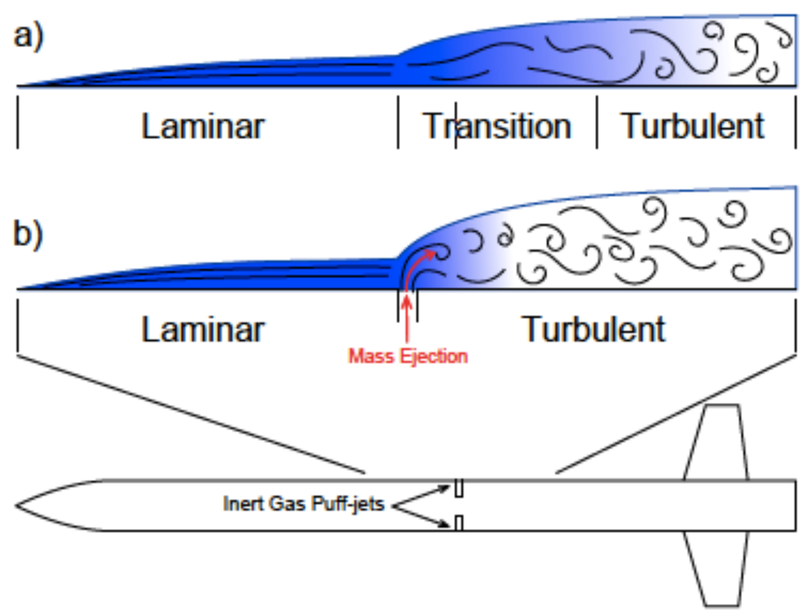
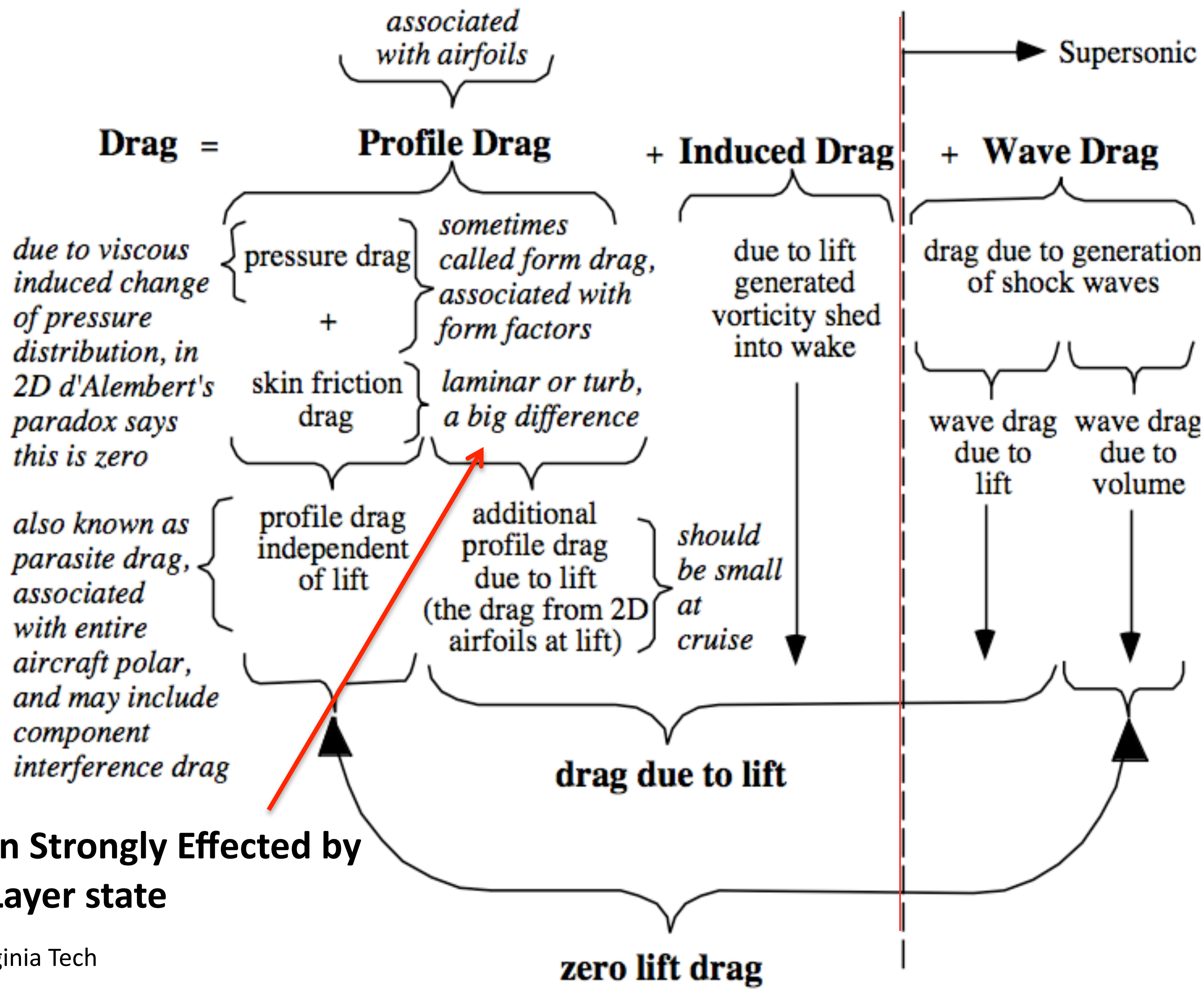


Figure 6: The effect of CARP system on boundary layer profile.

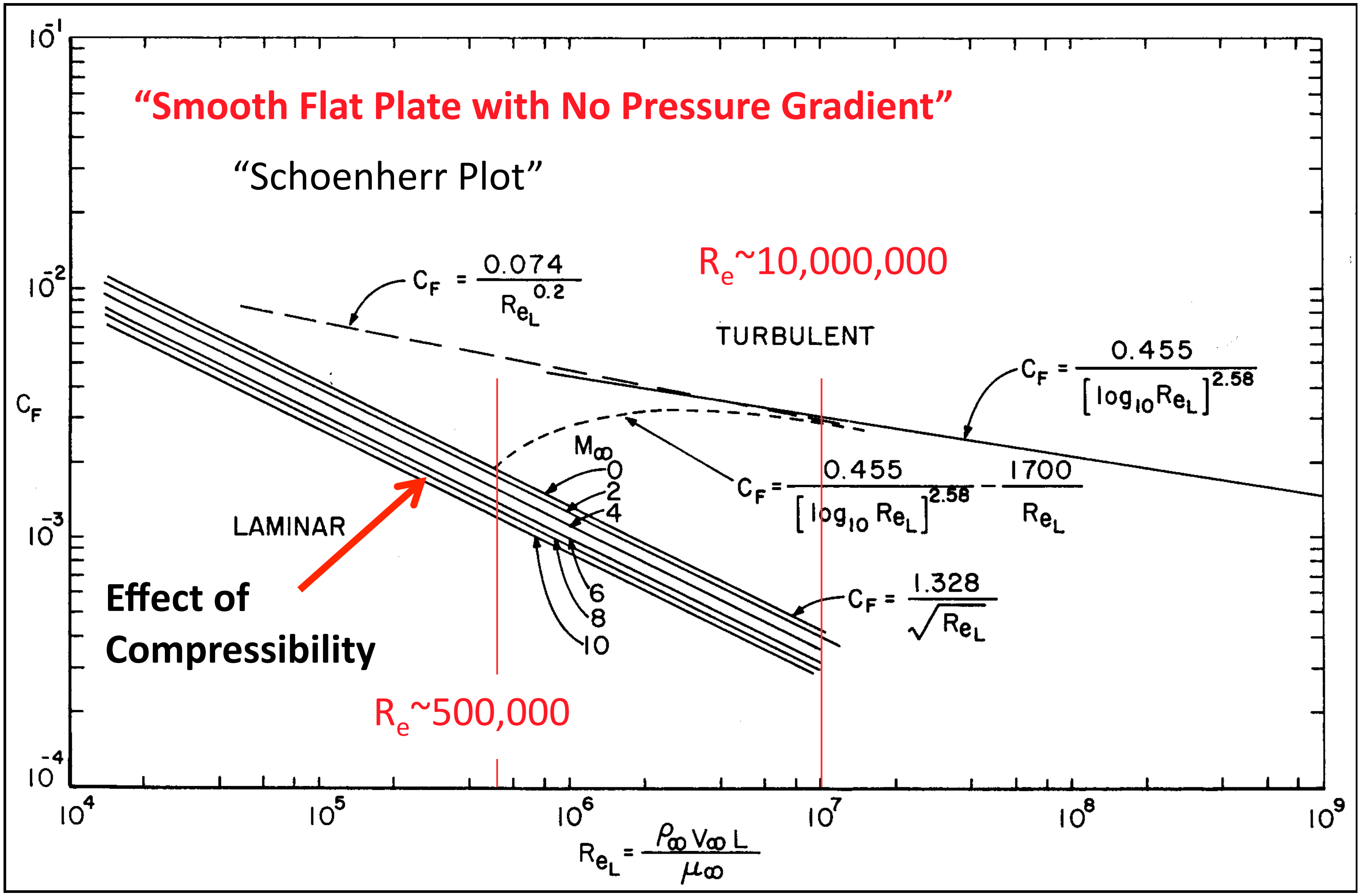
Types of Drag



Skin Friction Strongly Effected by Boundary Layer state

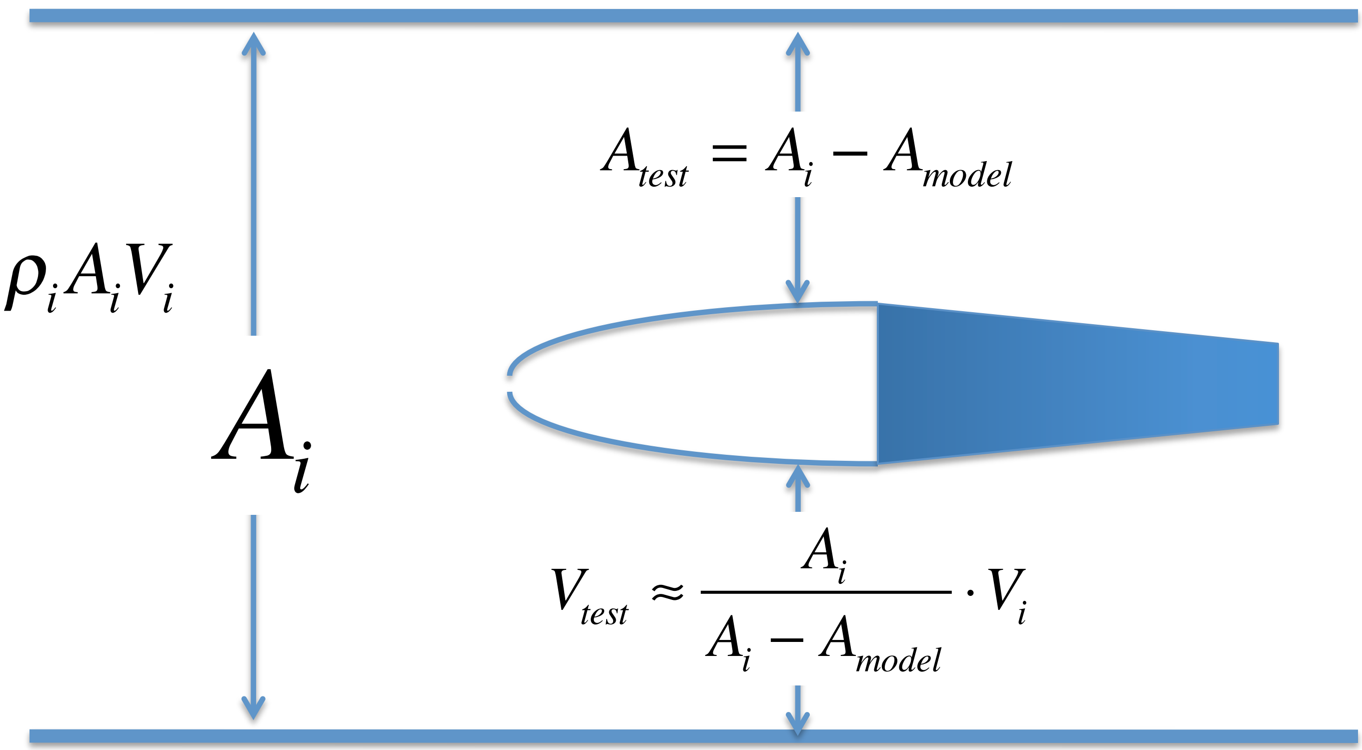
W.H. Mason, Virginia Tech

Empirical Skin Friction Correlations



Wind Tunnel Blockage Effects

$$\dot{m} = \rho_i A_i V_i$$



$$A_{test} = A_i - A_{model}$$

$$A_i$$

$$V_{test} \approx \frac{A_i}{A_i - A_{model}} \cdot V_i$$

Wind Tunnel Blockage Effects (2)

NASA Ames Blockage Criterion for Low Speed, Subsonic Flow

$$\frac{\text{maximum model cross-sectional area}}{\text{test section cross-sectional area}} \leq 1 - \frac{.25(3M+1)}{\left\{1 + \frac{[.25(3M+1)]^2 - 1}{4}\right\}^3}$$

$$1 - \frac{\frac{1}{4}(3(0.1)+1)}{\left(1 + \frac{\left(\left(\frac{1}{4}(3(0.1)+1)\right)^2 - 1\right)}{4}\right)^3}$$

$= 0.30558948$

Assumes Airspeed corrections for
Flow expansion around model

$$(C_D)_{corrected} = \frac{(C_D)_{measured}}{\left[1 + \frac{1}{4}\cdot\left(\frac{A_{model}}{A_{test\ section}}\right)\right]^2}$$

Herriot, John G.: Blockage Corrections for Three-Dimensional-Flow Closed-Throat Wind Tunnels, with Consideration of the Effect of Compressibility. NACA TR 990, 1950

Wind Tunnel Blockage Effects (3)

Example, 10% Model Blockage, Measured Airspeed 50 m/sec

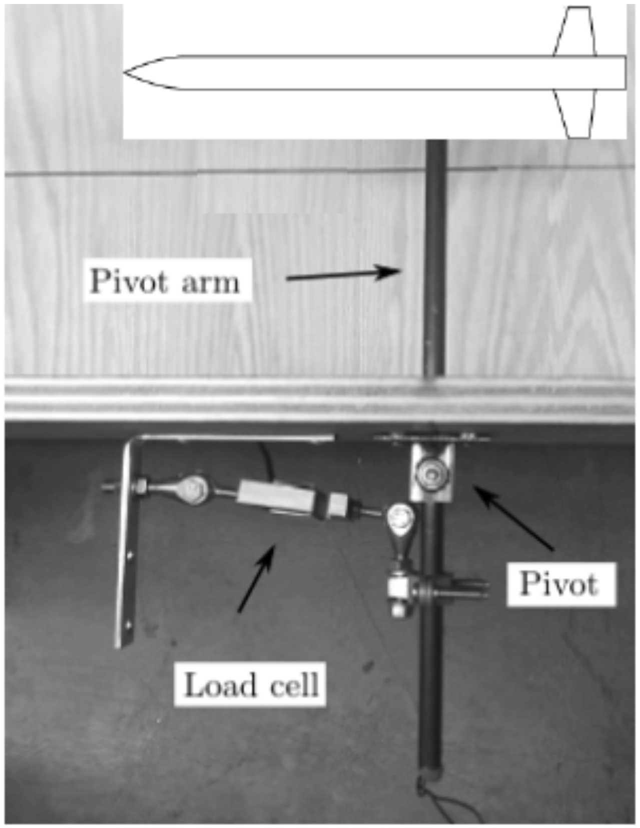
Actual airspeed at Model Maximum cross section … 55 m/sec

Measured Drag Coefficient = 0.4 … Corrected drag Coefficient

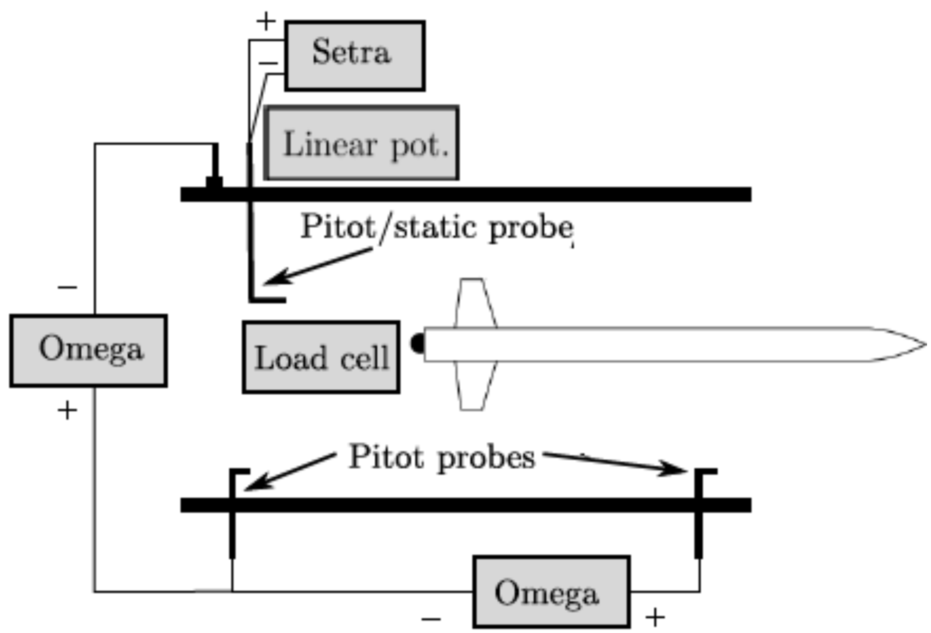
$$\left(C_D\right)_{corrected} = \left|\frac{1}{\left(1+\frac{1}{4}0.1\right)^2}0.4\right. = 0.38072576$$

Herriot, John G.: Blockage Corrections for Three-Dimensional-Flow Closed-Throat Wind Tunnels, with Consideration of the Effect of Compressibility. NACA TR 990, 1950

Wind Tunnel Instrumentation

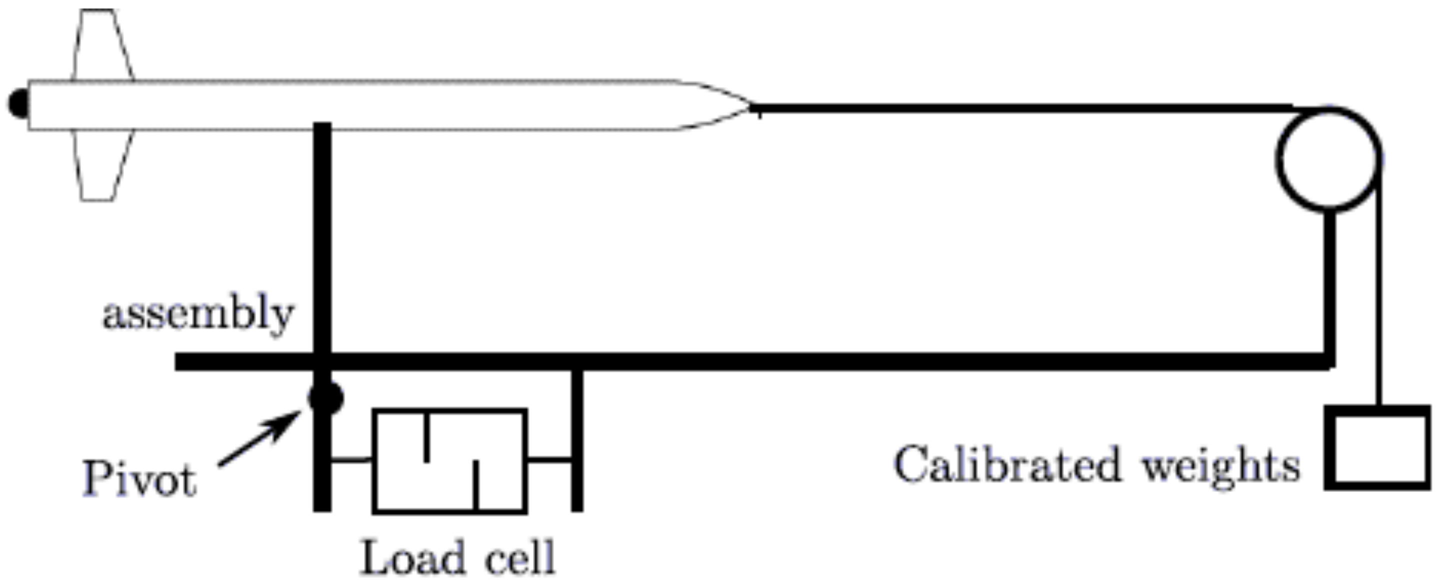


installation, pivot arm and load cell configuration.



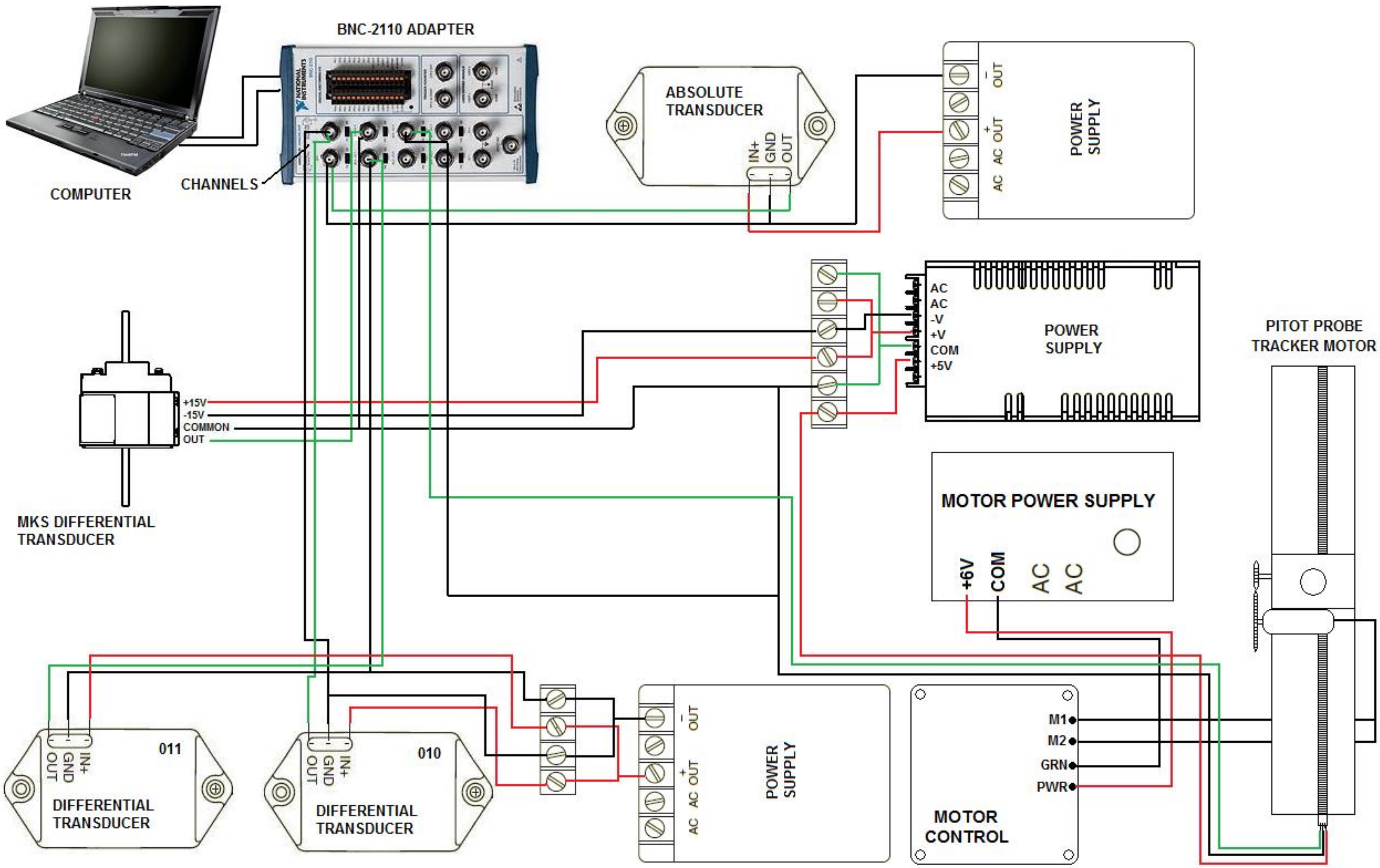
Block diagram of mechanical measurements.

Wind Tunnel Instrumentation (2)



In situ calibration of load cell using calibrated weights.

Wind Tunnel Instrumentation (3)



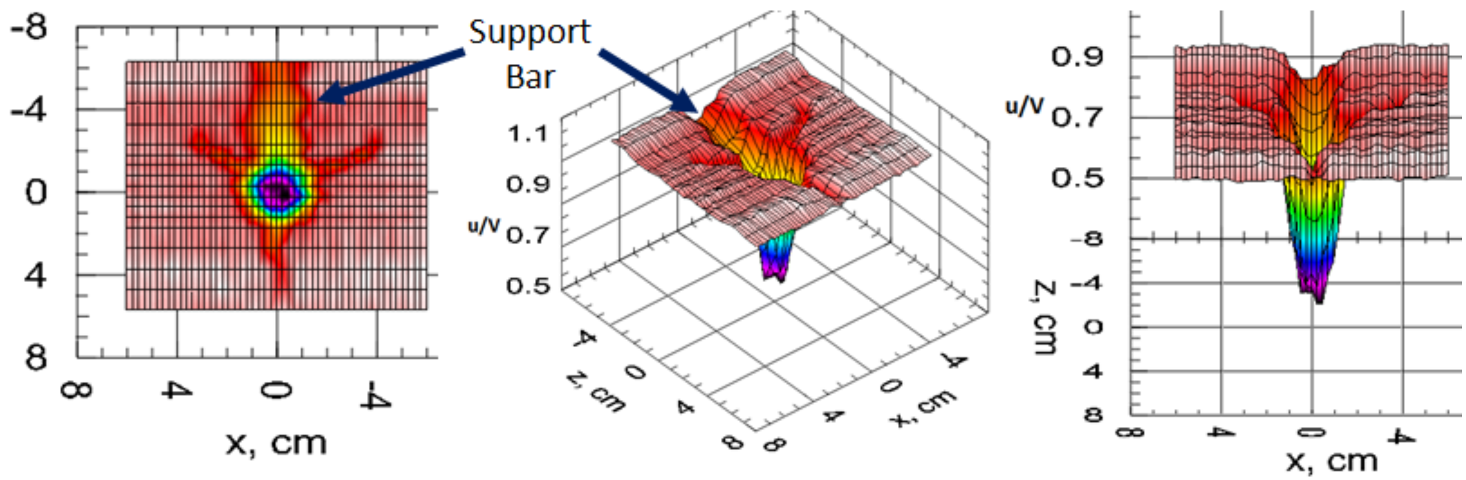
Wind Tunnel Instrumentation (4)

Table 1: List of transducers and their respective function and specifications

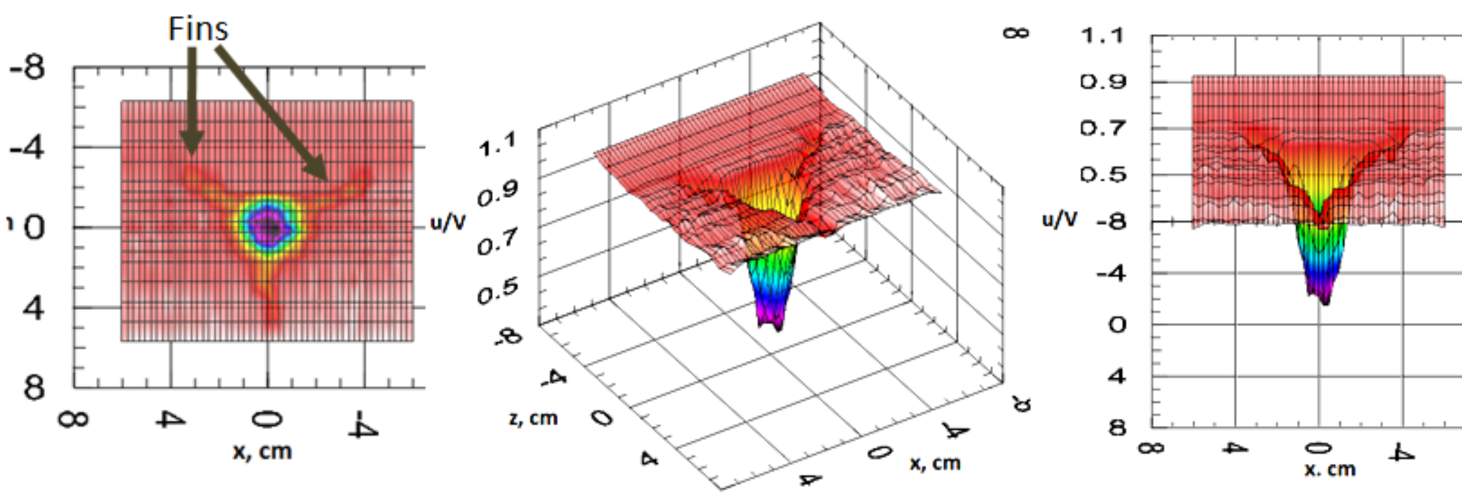
Make/Model Number	Measurement	Function	Range	Accuracy
Omega PX143-01BD	Differential pressure	Tunnel loss	±6.9 kPa (1 psi)	0.03% FS*
Omega PX143-01BD	Differential pressure	Free stream velocity	±6.9 kPa (1 psi)	0.03% FS*
Setra Datum 2000 model 2239	Differential pressure	Velocity profile	0 - 3.7 kPa (0.54 psi)	0.14% FS*
Omega LCCD-25	Force	Propeller thrust	±111 N (25 lbf)	0.2% FS*
Fluke i30	Current	Motor current	0.03 - 30A	1% of reading
Shimpo DT-209X	Rotation rate	Motor RPM	6.0 - 99,999 RPM	±1 RPM

*As measured from calibration data

Wake Survey Results



Wake survey normalized, raw pressure data.



Wake survey normalized, filtered pressure data.


Questions??