Facility Dynamics Engineering

Controlling Variable Air Volume Systems

Flow and Pressure Measurement

Presented By:

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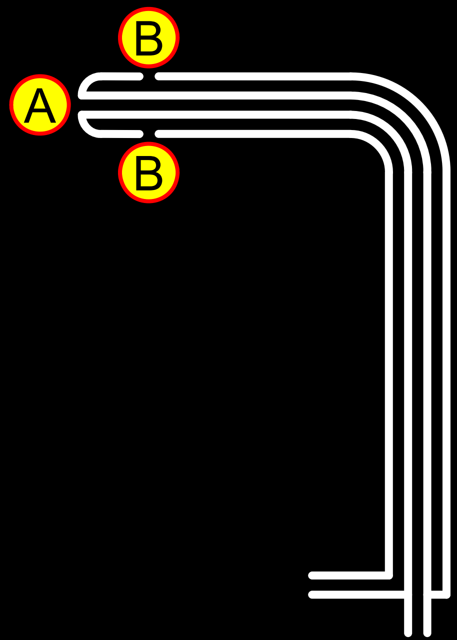
Flow Sensors are Typically a Form of Pitot Tube



Pitot tubes are designed to measure velocity pressure

A tube inside a tube

- Inner tube open at the tip A
- Outer tube open through ports B on the side

In a moving air stream:

- The ports on the side (B) are exposed to only the ambient static pressure
- The port on the tip (A) is exposed to both the static pressure and the pressure created by the air being stopped; a.k.a. total pressure.
- The air is stopped because the tube dead ends on the measurement device
- The pressure associated with the moving air is called velocity pressure

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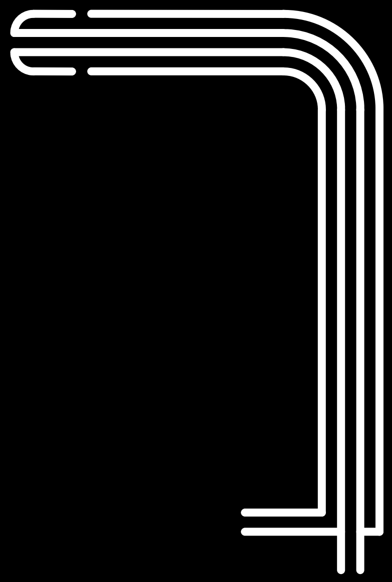

There is a specific relationship between velocity and velocity pressure

$$V = 4{,}005\sqrt{p_{velocity}}$$

Where:

$p_{velocity}$ = Velocity pressure in inches water column

V = Velocity in feet per minute

4,005 = A units conversion constant

(Which depends on the state of the air!)

If you measure the velocity pressure, then you can calculate the velocity

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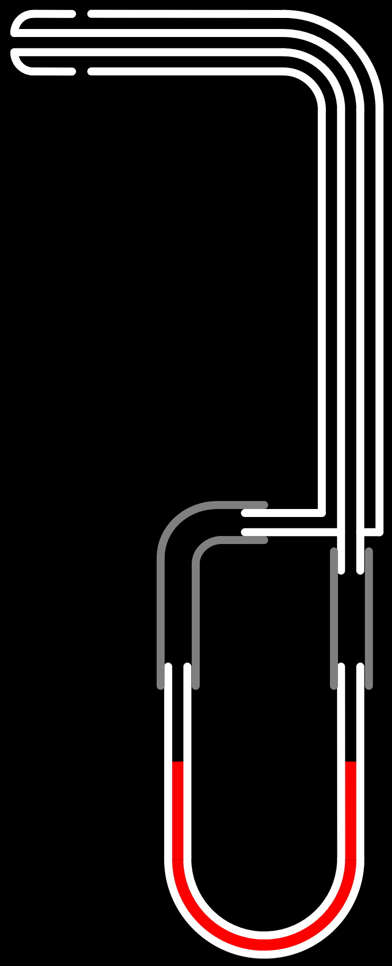

Connecting a U shaped glass tube filled with a liquid like oil or water – called a manometer – to the pitot tube allows velocity pressure to be measured

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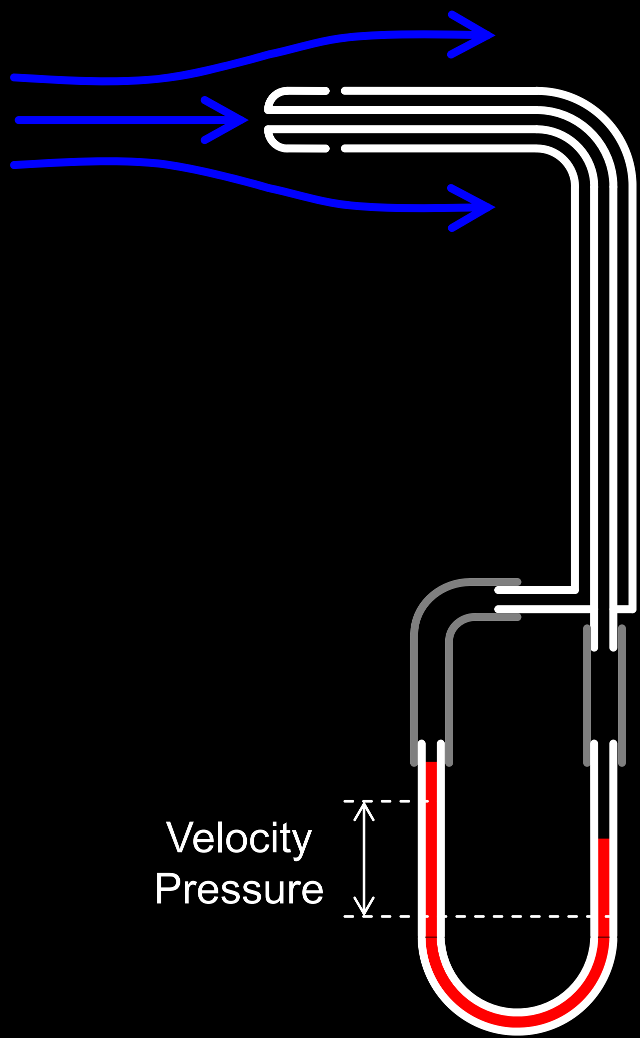

With no air flow, the pressure at both ports is the same and the level in each "leg" of the U tube is the same.

In a moving air stream, the total pressure port pushes the manometer liquid down in the tube it is connected to

But the static pressure pushes back, canceling out the static pressure portion of the total pressure signal

The resulting level difference is a measure of the velocity pressure

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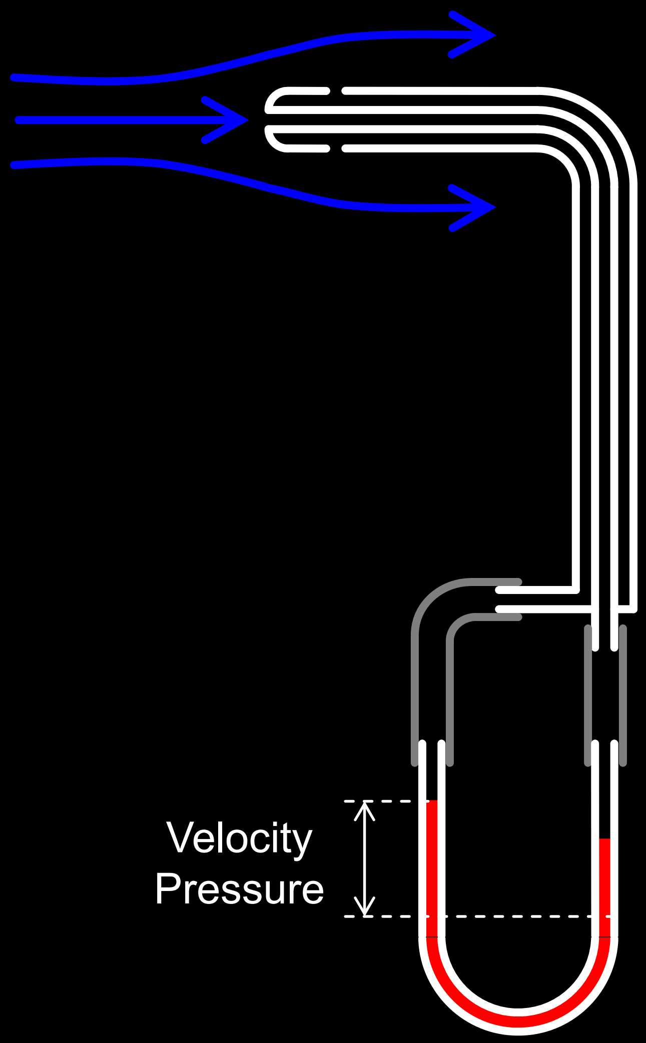

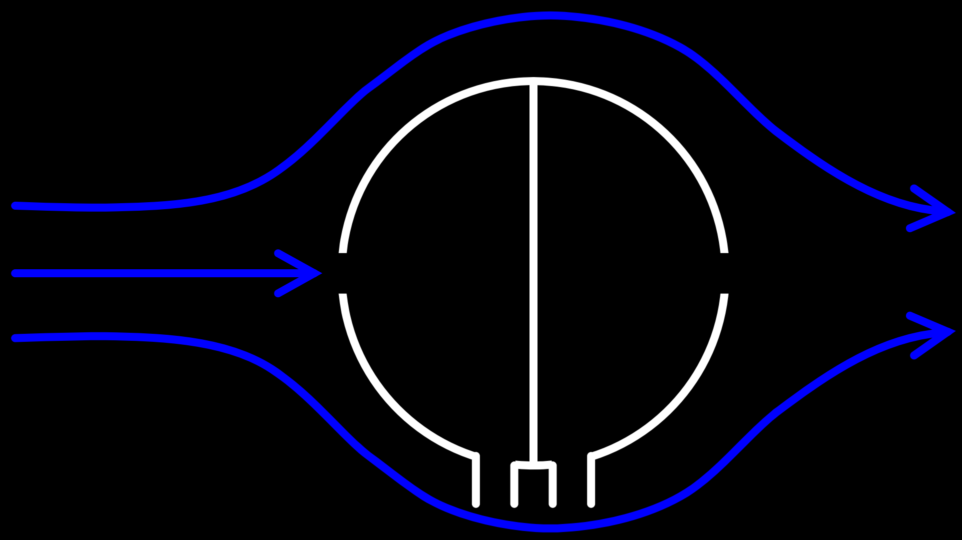

Terminal unit flow sensors are typically tubes that are divided down the center, creating two chambers

- One chamber has a port facing into the air flow
- The other has a port facing away from the air flow

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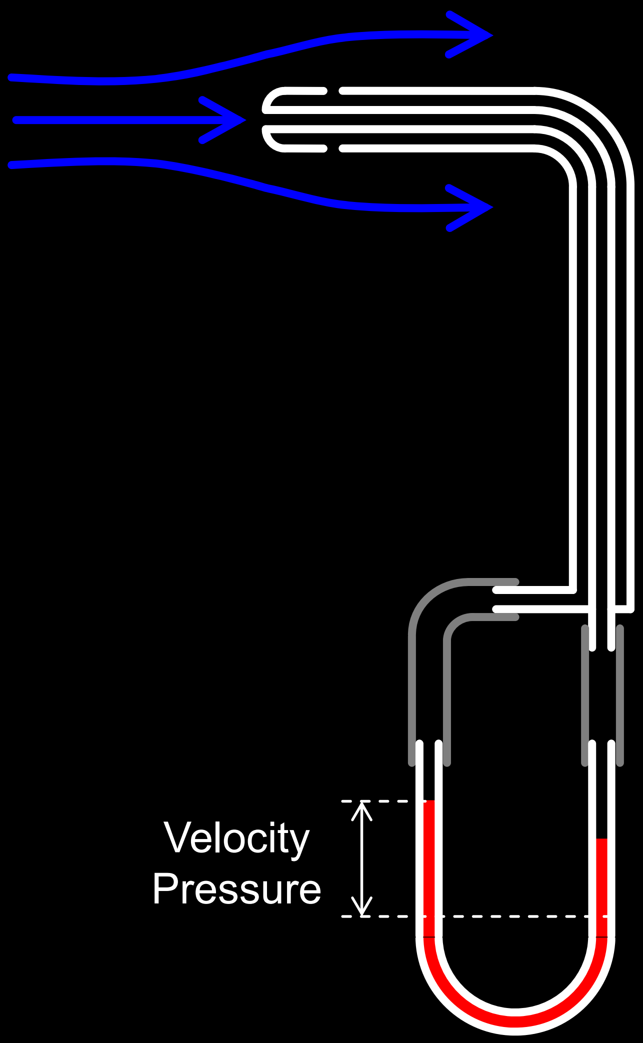

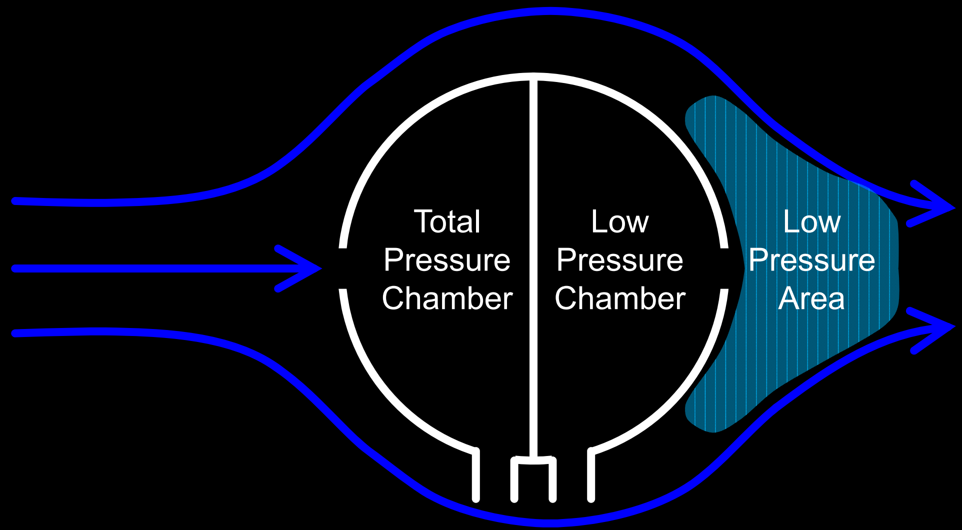

The chamber facing the air flow sees total pressure

The chamber facing away from the air flow sees a low pressure area in the wake of the flow around the tube

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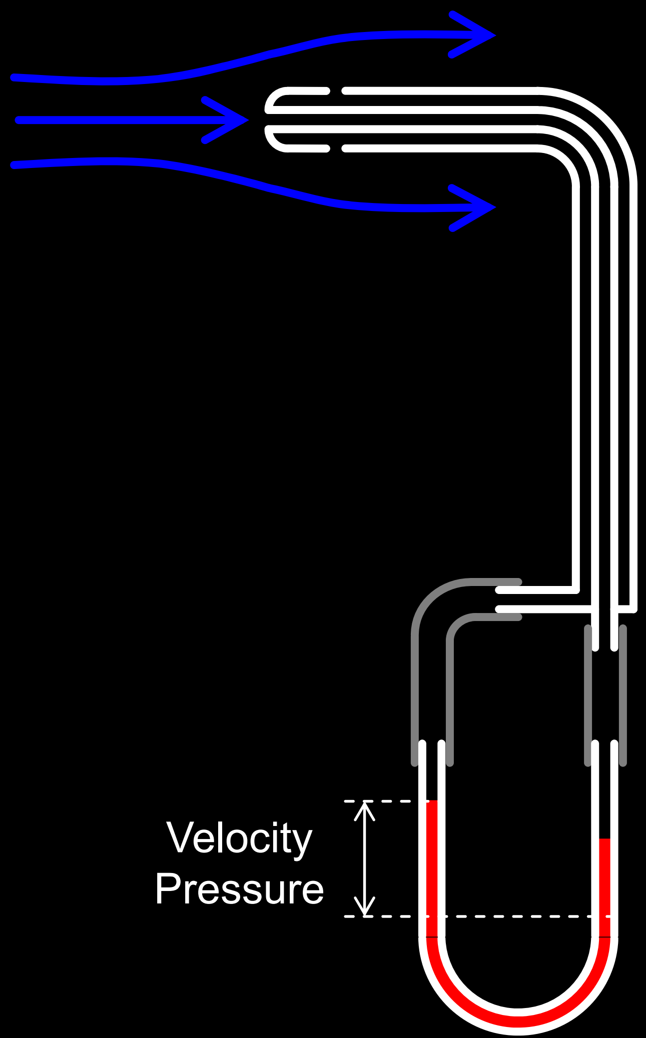
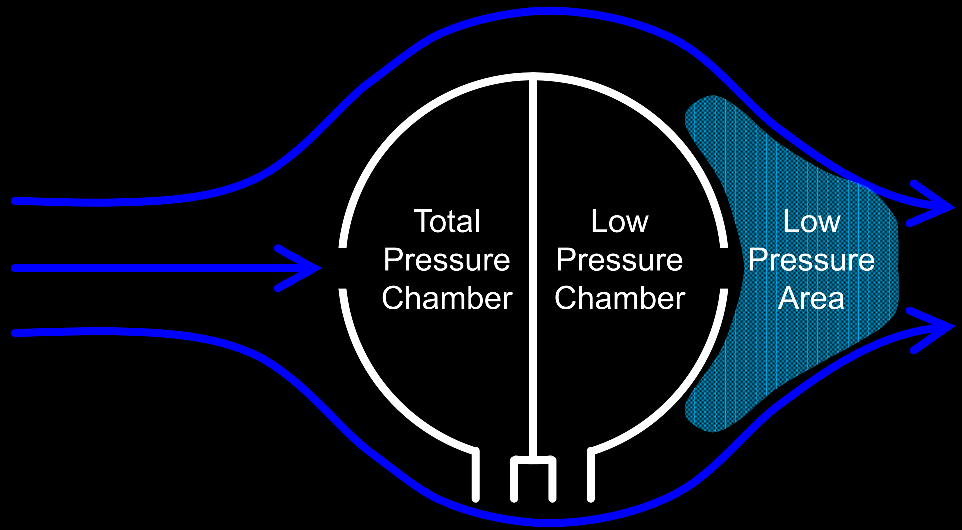


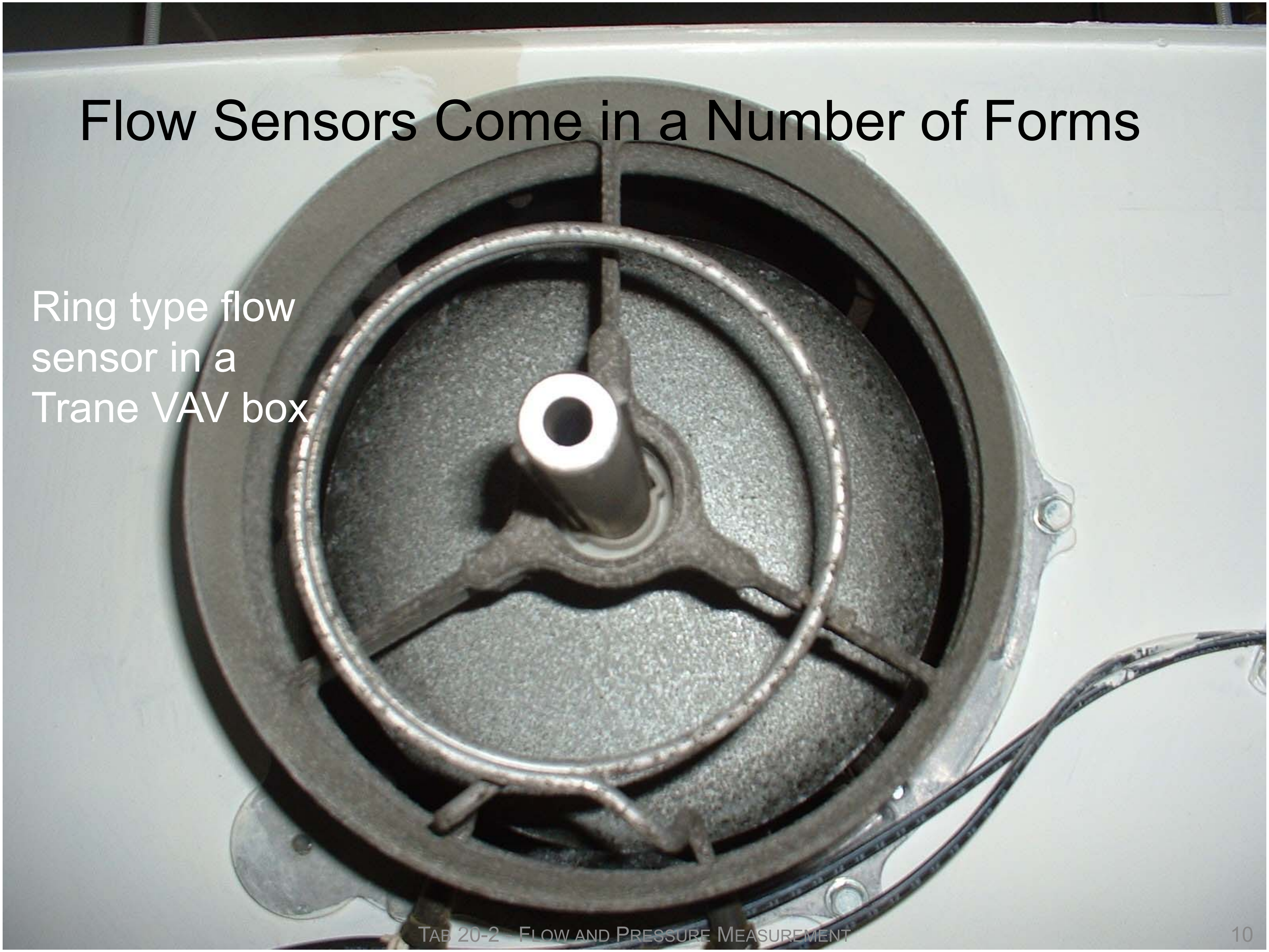


- The difference between the two pressures is an "amplified velocity" pressure signal
- The "amplification" allows the VAV box controller to work at lower flows than would be possible if actual velocity pressure were sensed

Flow Sensors Come in a Number of Forms

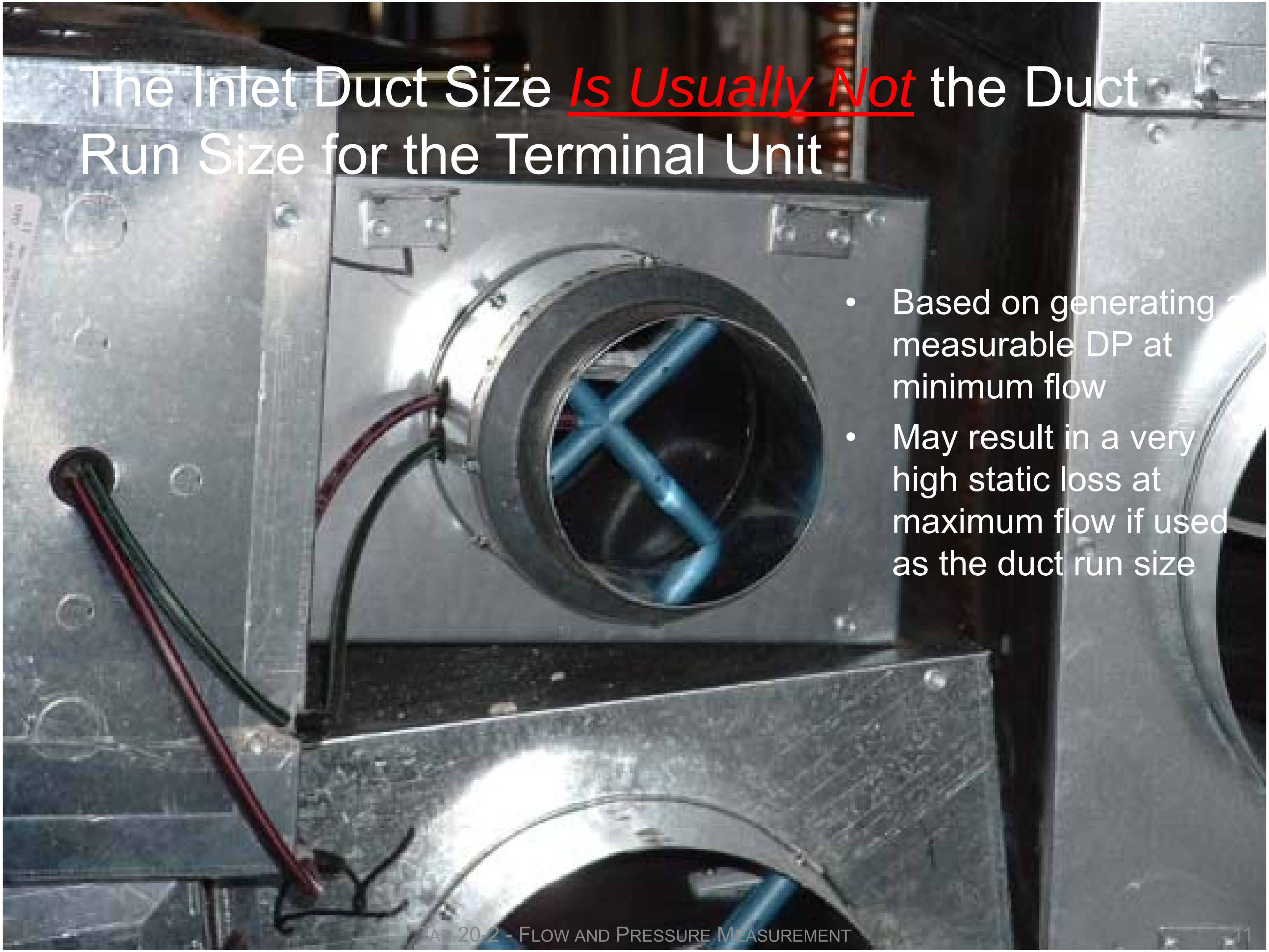
Titus Double Duct Box with cross type flow sensor

Flow Sensors Come in a Number of Forms

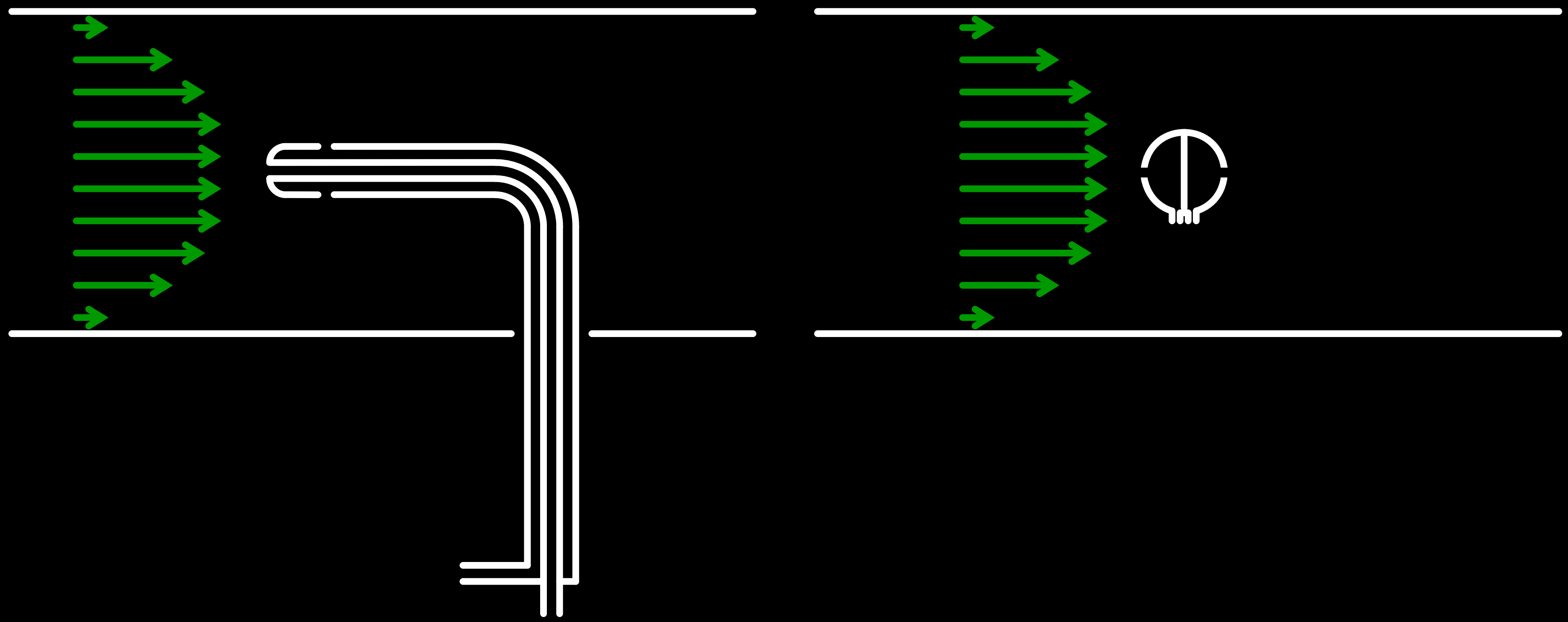


Ring type flow sensor in a Trane VAV box

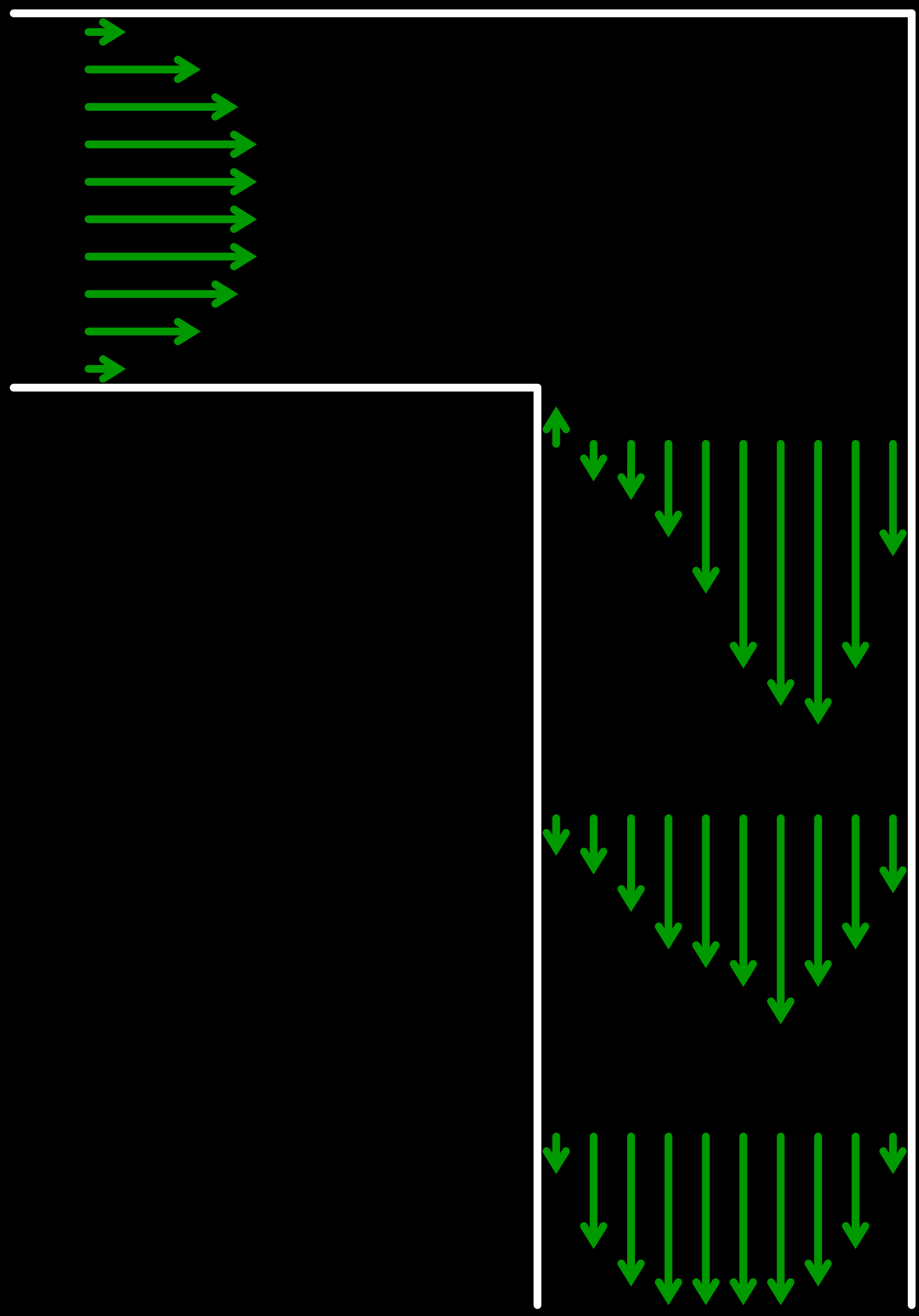
The Inlet Duct Size *Is Usually Not* the Duct Run Size for the Terminal Unit



- Based on generating a measurable DP at minimum flow
- May result in a very high static loss at maximum flow if used as the duct run size



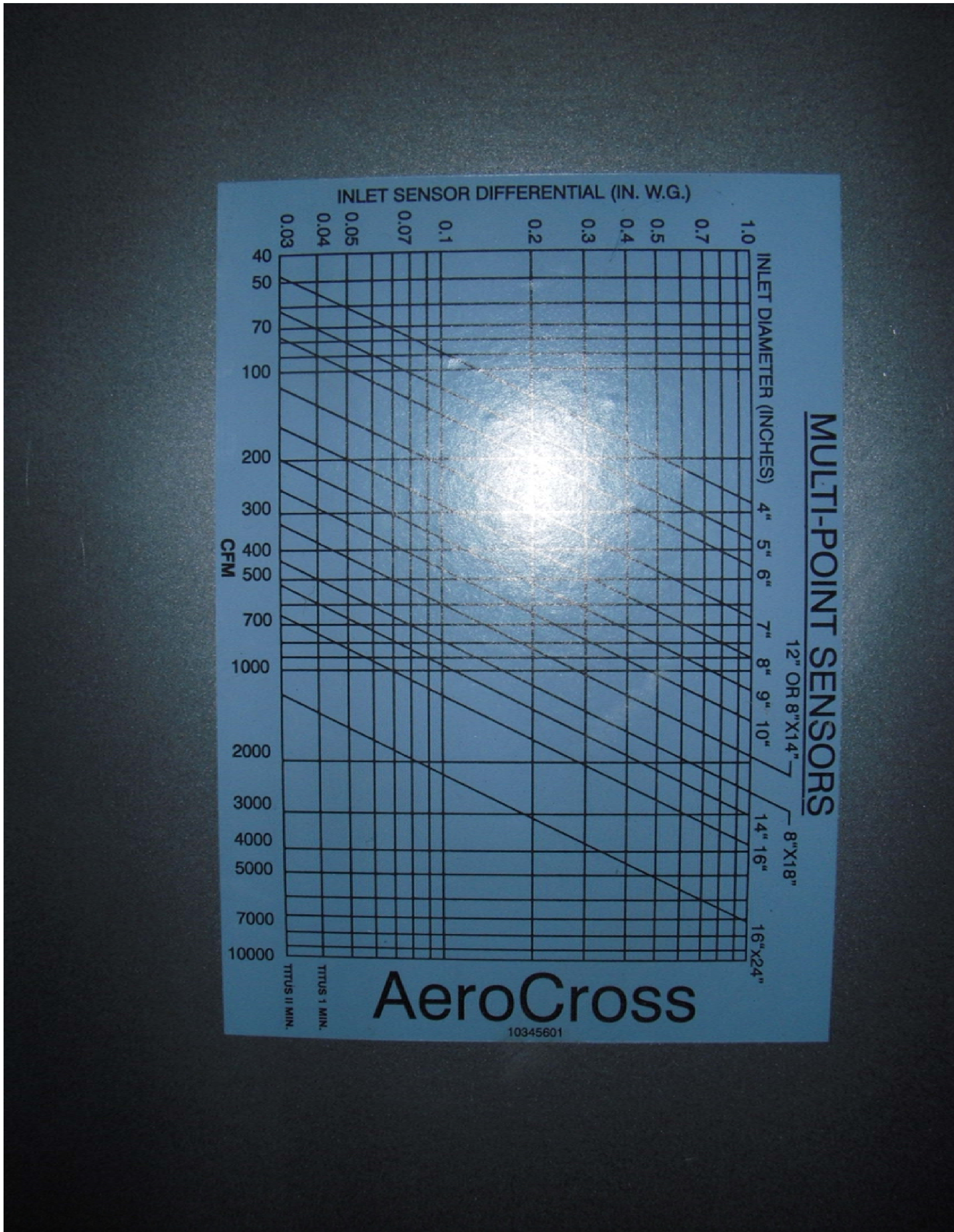
Pitot tubes and VAV flow sensors rely on a uniform velocity profile for accurate measurements



- Turns and other obstructions distort the flow profile
- Interactions between the air and the duct wall will eventually restore the uniform flow profile
- Generally takes 5-10 equivalent duct diameters of distance

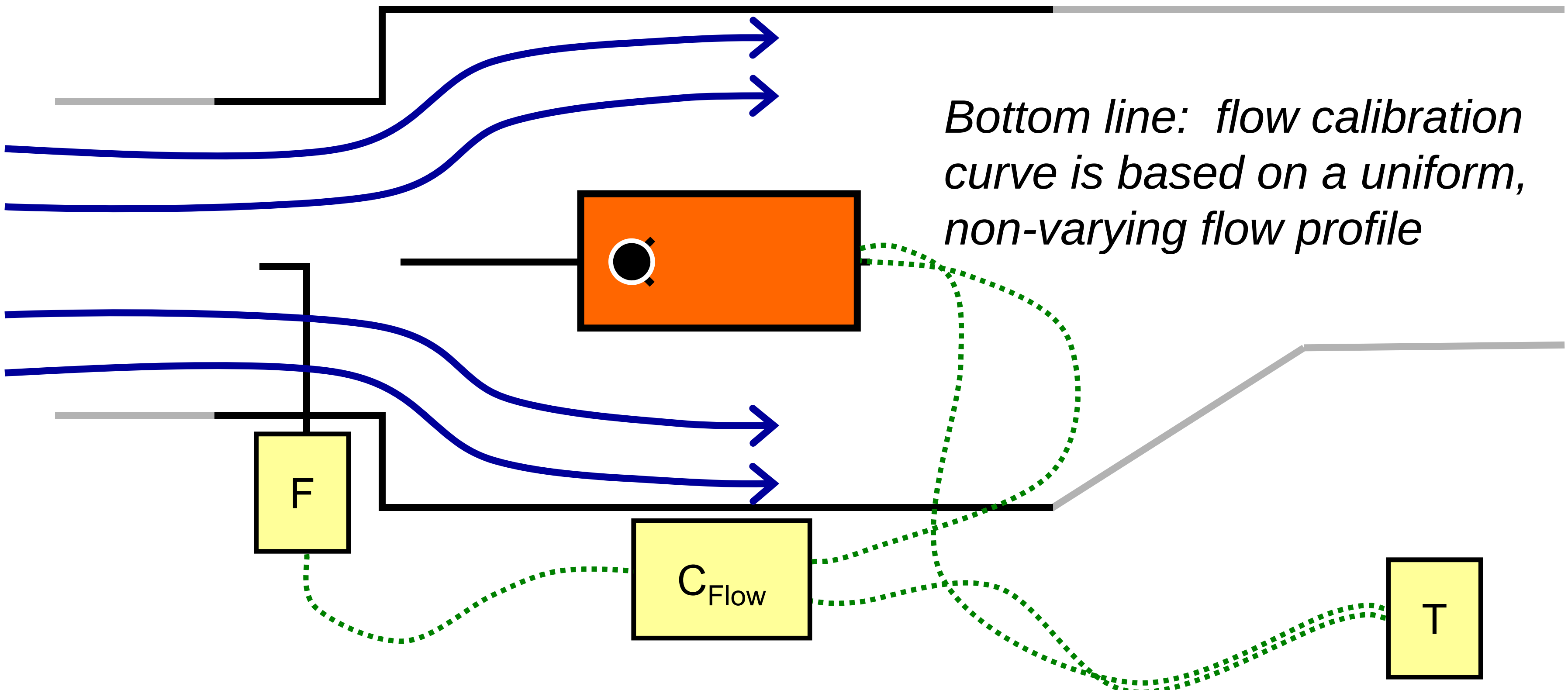

Typical Terminal
Unit Inlet Duct
11/14/2002

Typical Terminal Unit Flow Calibration Chart



Typical Terminal Unit Flow Calibration Chart

Flow Calibration; One Point *Doesn't* Fit All



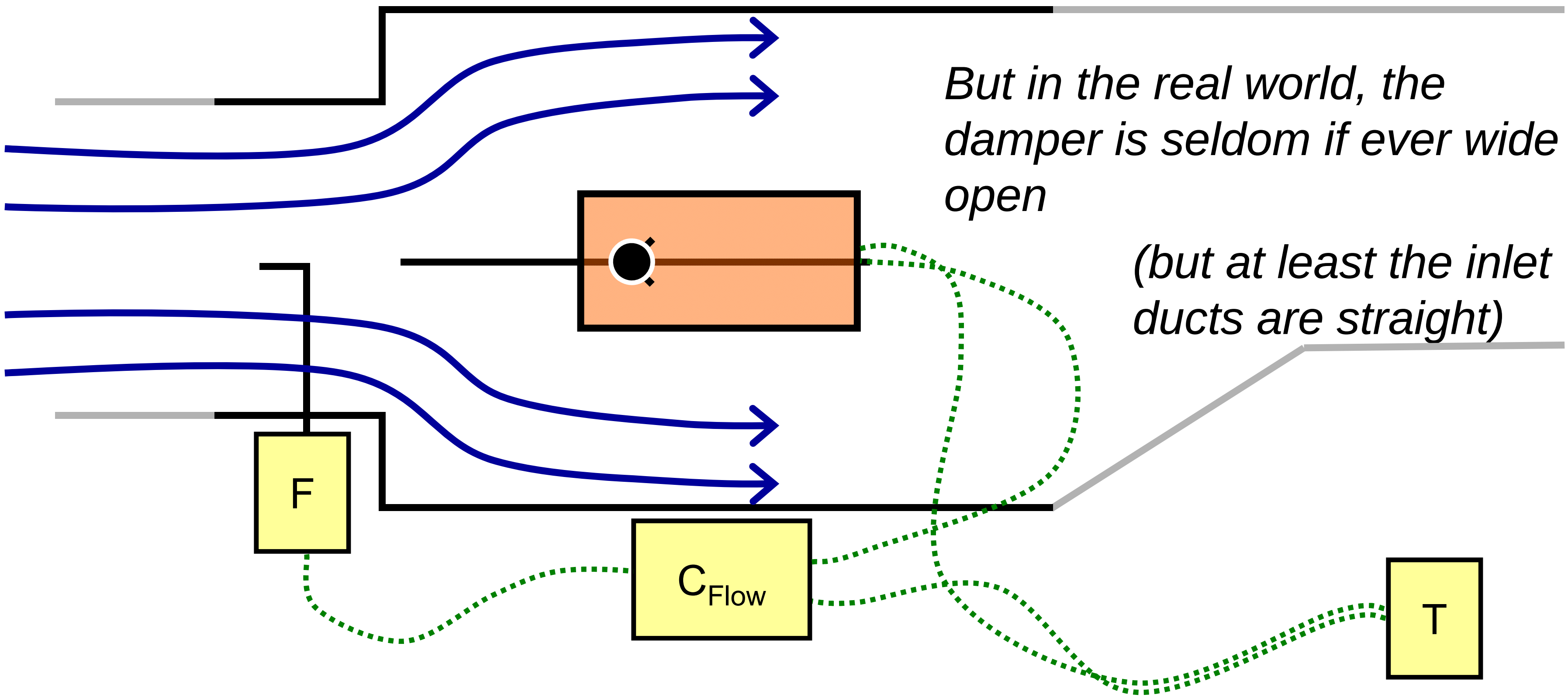
Bottom line: flow calibration curve is based on a uniform, non-varying flow profile

Flow sensors calibration curves established by factory test

Damper held fully open for the entire flow range

Flow varied by varying fan speed on the fan in the test rig

Flow Calibration; One Point *Doesn't* Fit All

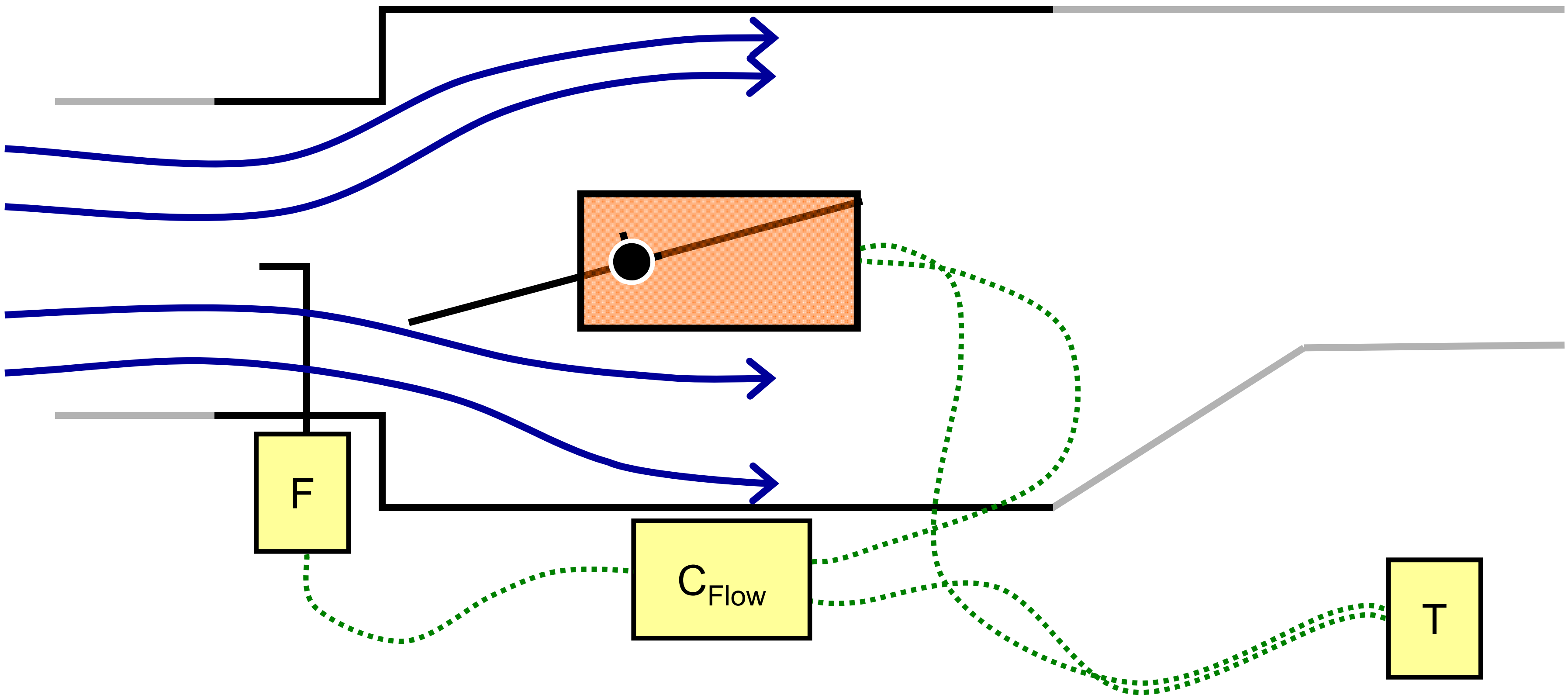


But in the real world, the damper is seldom if ever wide open

(but at least the inlet ducts are straight)

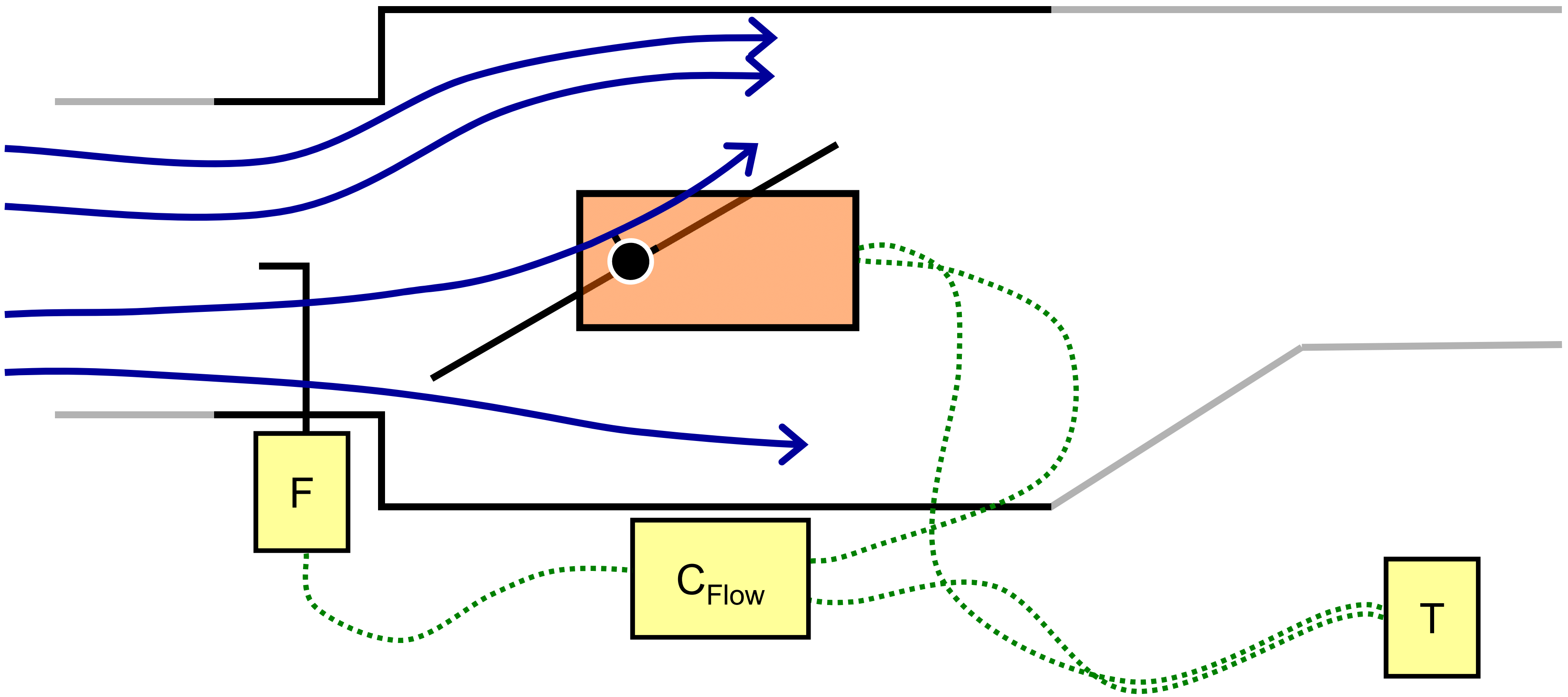
In the real world, with a good inlet condition and a wide open damper, things tend to match up pretty well

Flow Calibration; One Point *Doesn't* Fit All



As the terminal unit damper begins to throttle the flow profile upstream of it begins to distort because the air is directed towards the sides of the box and accelerated by the closing damper

Flow Calibration; One Point *Doesn't* Fit All



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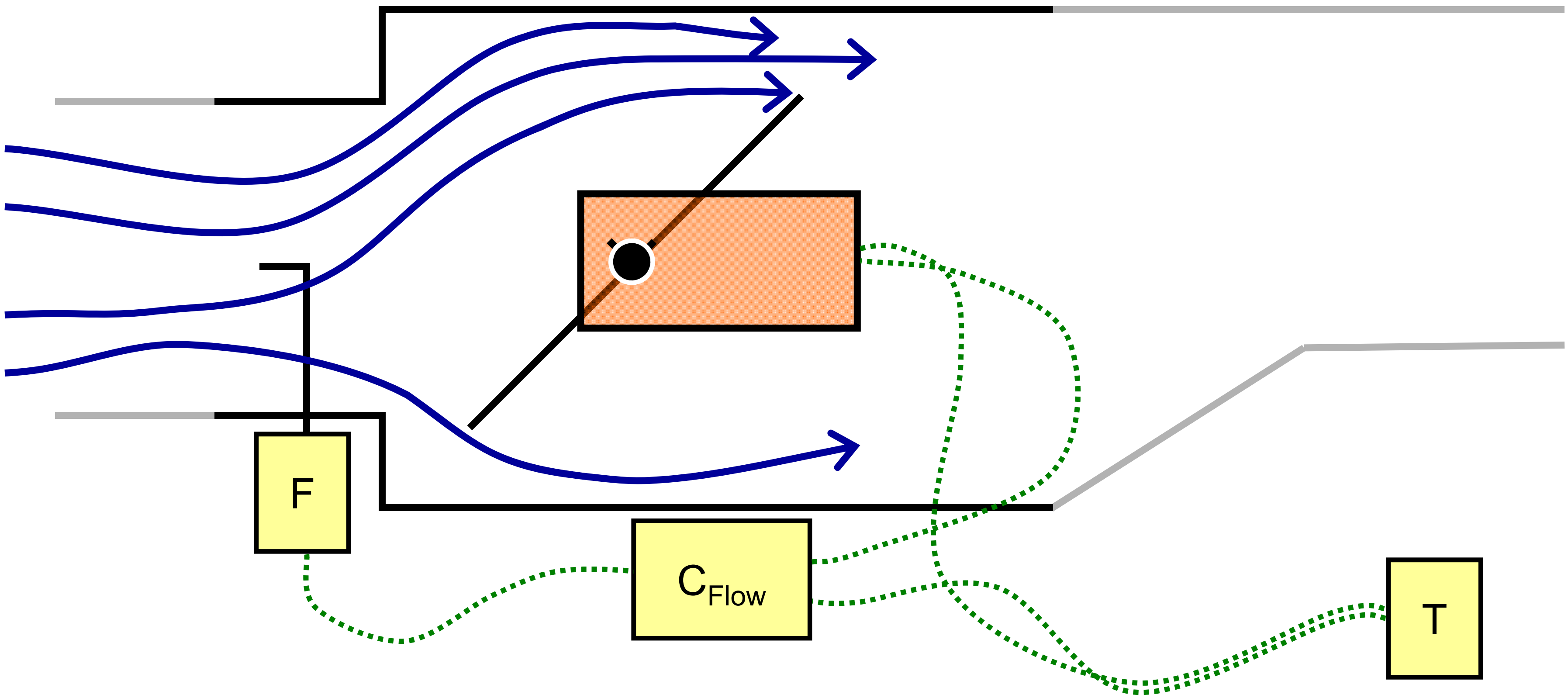

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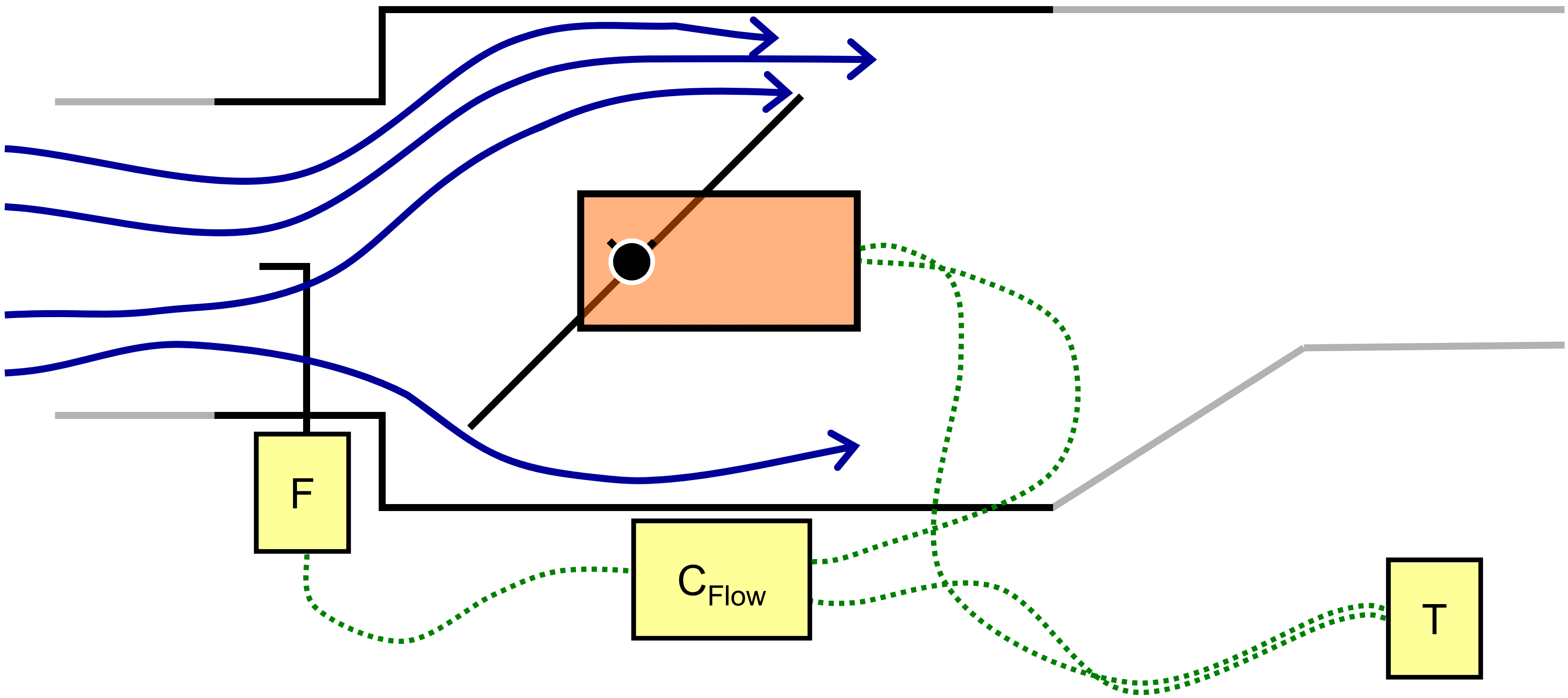
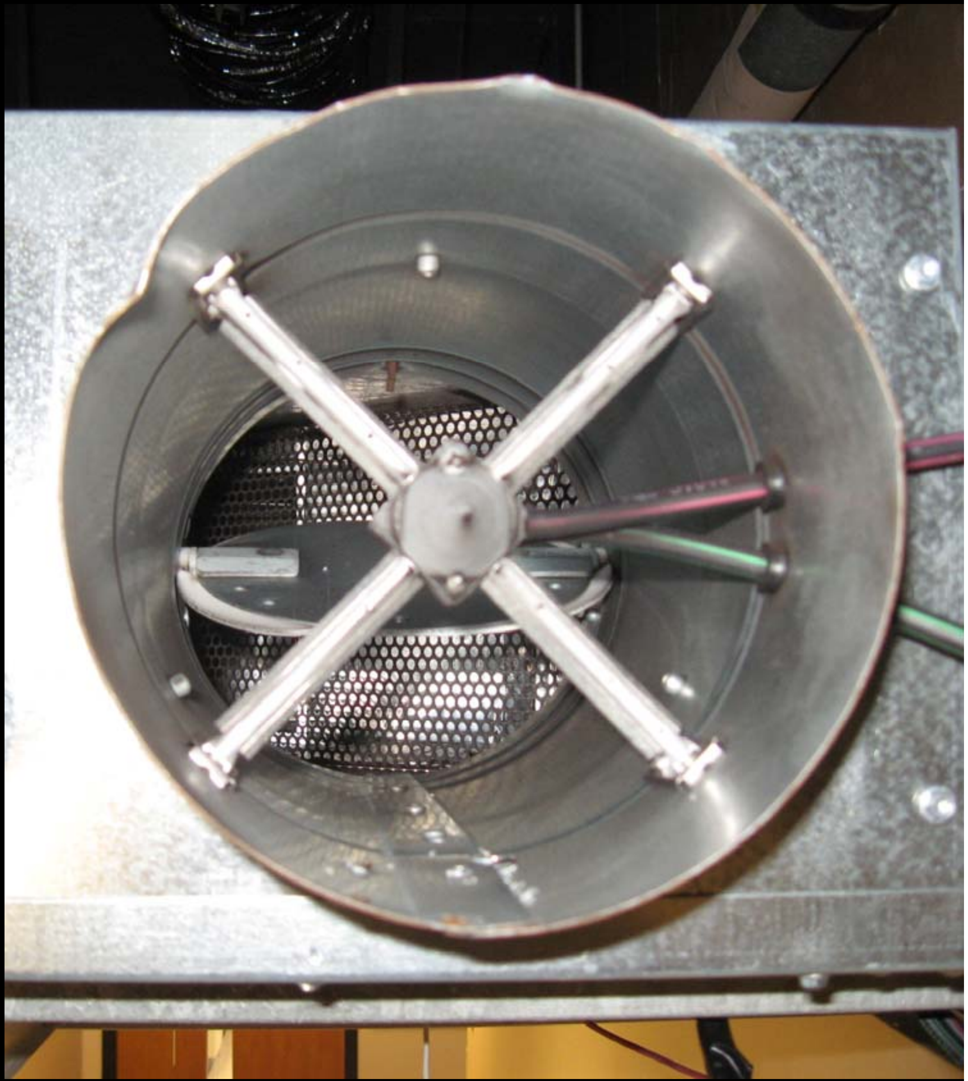


Calibrations based on at least two data points representative of the actual extreme operating conditions of the terminal unit will generally provide better results vs. a one point calibration

Field Data from the "Show Me" State

Building Control System Data	
Set point	1,800 cfm
Indicated Flow	1,835 cfm
	(102% of set point)
Set point	700 cfm
Indicated flow	717 cfm
	(102% of set point)

Field Test Data (Traverse basis)	
Set point	1,800 cfm
Traversed flow	1,962 cfm
	(107% of indicated)
Set point	700 cfm
Traversed flow	1,125 cfm
	(157% of indicated)



Field Data from the “Show Me” State

Read the paper and the presentation from NCBC 2013 at http://tinyurl.com/RonNCBC2013Presentation and

http://tinyurl.com/RonNCBC2013Paper

The Relationship Between Velocity and Velocity Pressure

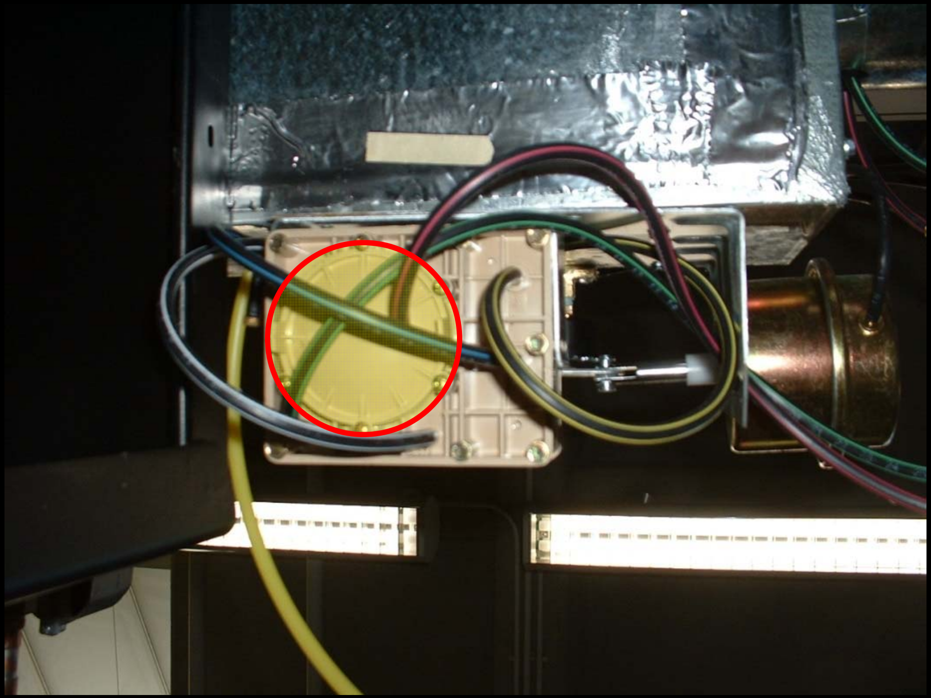
12 inch VAV Box

- Maximum flow
  - 2,000 cfm
  - VP = .2494 in.w.c.
- Minimum flow
  - 325 cfm
  - VP = .0066 in.w.c.

The Relationship Between Velocity and Velocity Pressure

12 inch VAV Box

- Maximum flow
  - 2,000 cfm
  - VP = 0.2494 in.w.c.
  - Force = 0.0465 lb
  - Force = 0.74 oz
- Minimum flow
  - 325 cfm
  - VP = 0.0066 in.w.c.
  - Force = 0.0017 lb
  - Force = 0.03 oz



Pneumatic Terminal Failure Modes

- Flow set points drift up
- Recent experience
  - Sample 10 of 45 pneumatic zones
  - Three years since last service effort

- Many of the controllers worked
- Many thermostats were out of calibration
- 0 (zero) zones were regulating at the required flow
- Many zones were wide open
- Some reheat valves were leaking through

Pneumatic Zones = Opportunity

Troubleshooting Pneumatic Terminal

Troubleshooting DDC Terminal