A New Orifice Flow Rate Equation

Oil and Gas Focus Group

26th May 2021

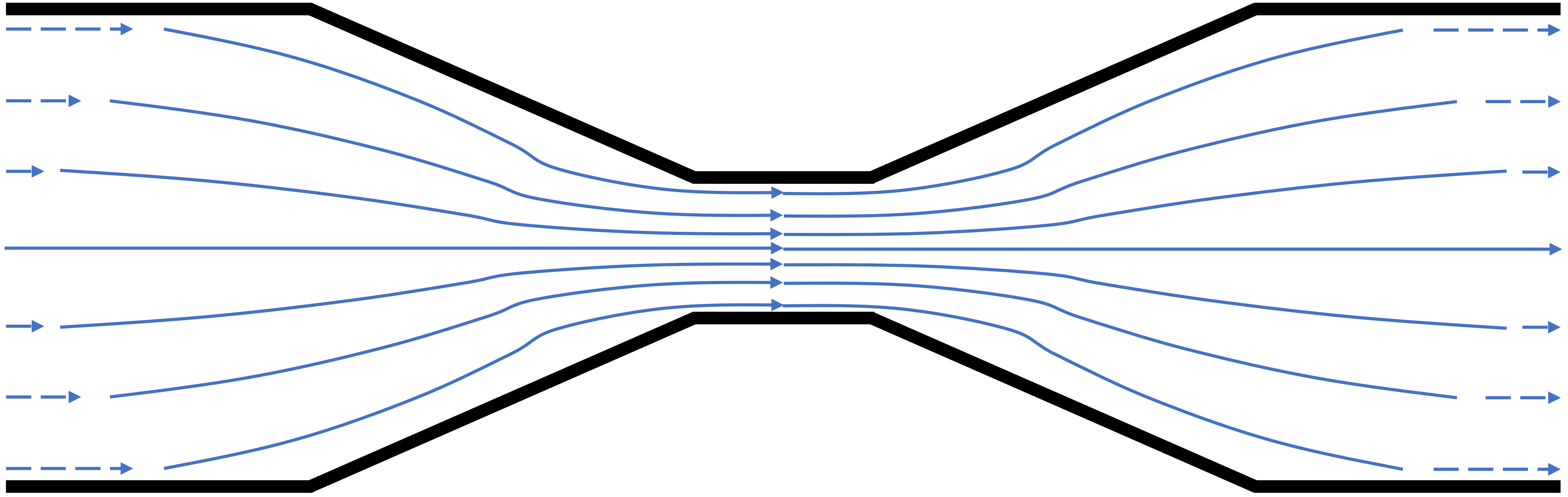
Agenda

- Venturi
- Orifice Plate
- Three DPs
- m_{new} New Equation
- Does it work?
- What's it for?

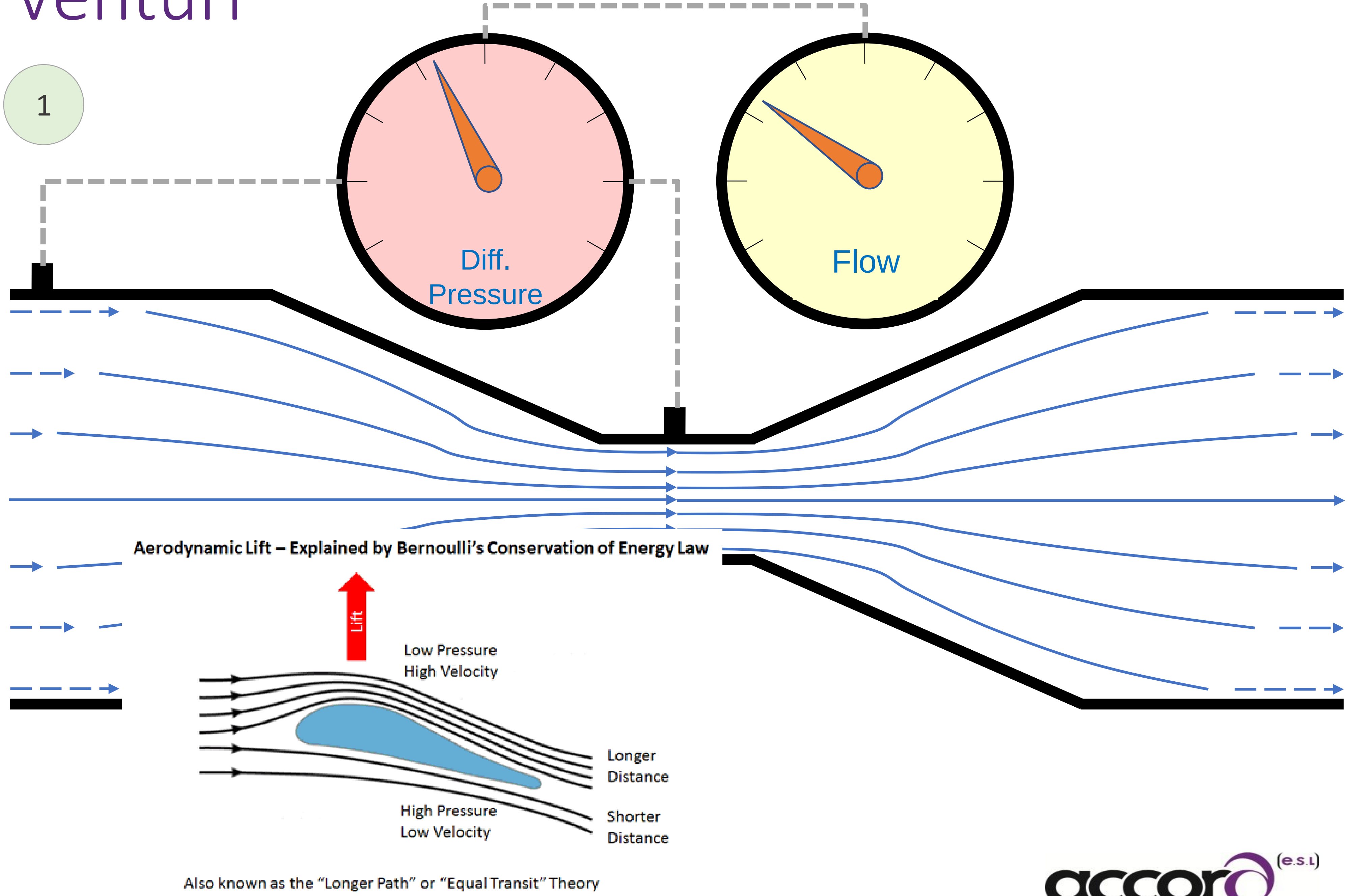
Agenda

Venturi

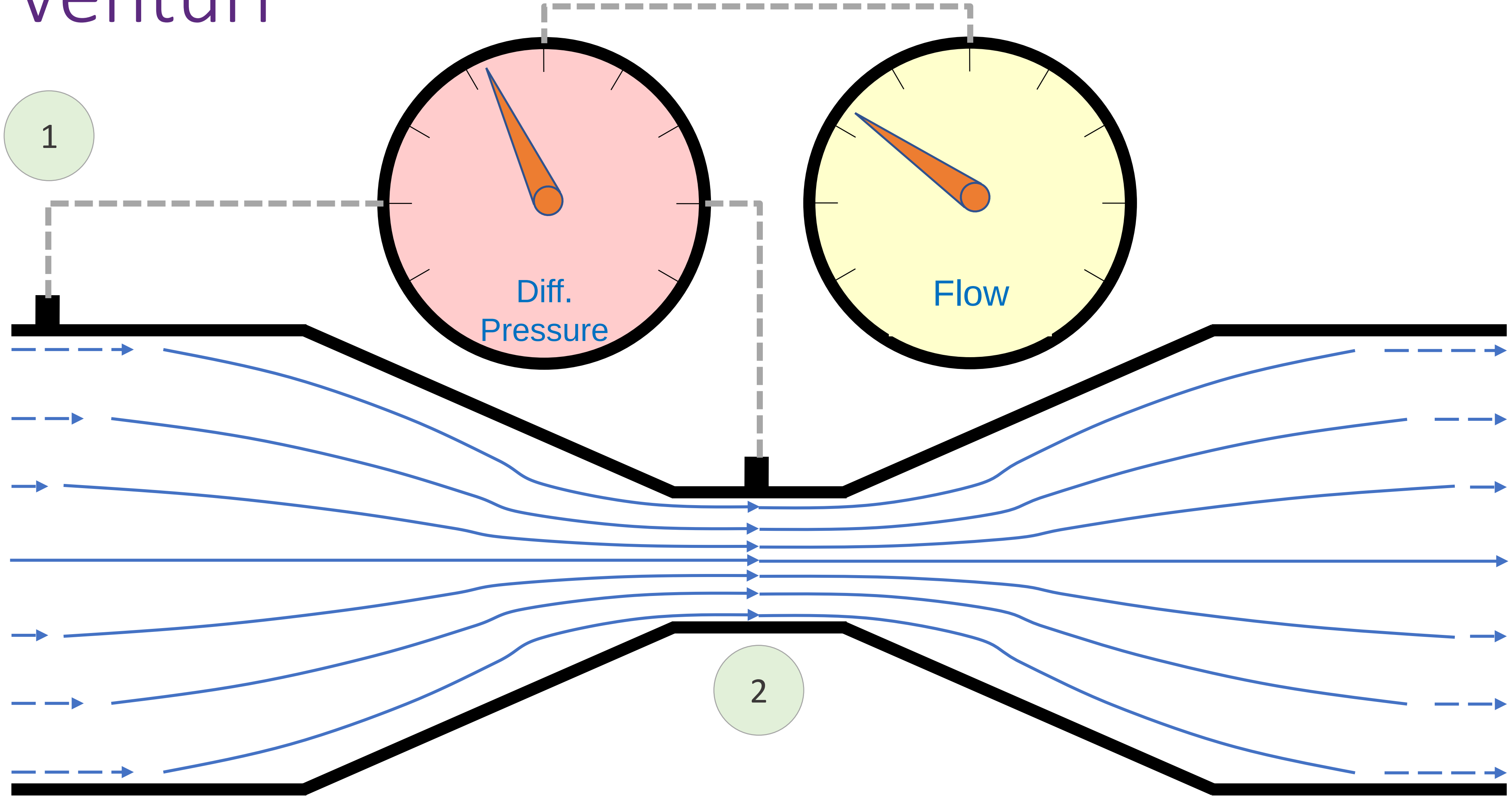
Venturi



Venturi


1
Diff.
Pressure
Flow
Aerodynamic Lift – Explained by Bernoulli's Conservation of Energy Law
Lift
Low Pressure
High Velocity
Longer
Distance
High Pressure
Low Velocity
Shorter
Distance
Also known as the "Longer Path" or "Equal Transit" Theory

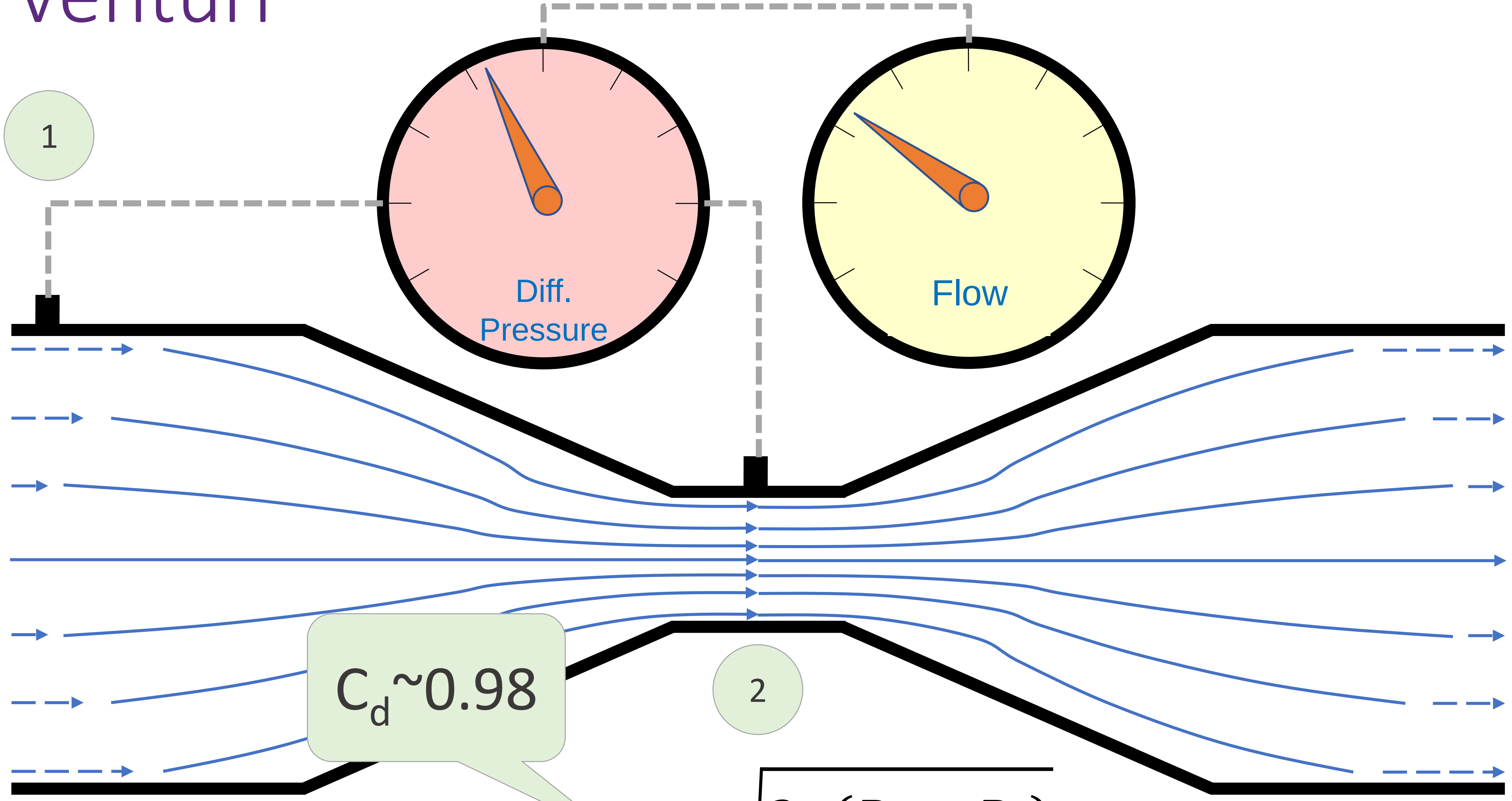
Venturi



"Energy" Conservation

Mass Conservation

Venturi



$$m = A_2 \sqrt{\frac{2\rho(P_1 - P_2)}{1 - \left(\frac{A_2}{A_1}\right)^2}}$$

Agenda

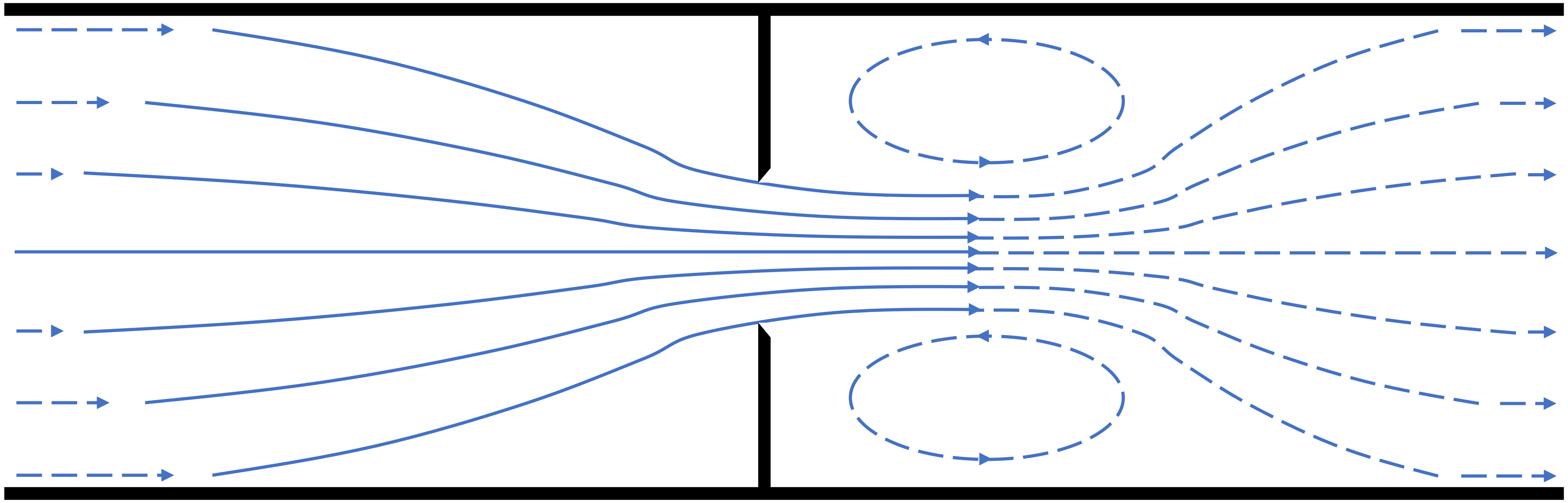
Venturi

Orifice Plate

Orifice

C_d~0.6

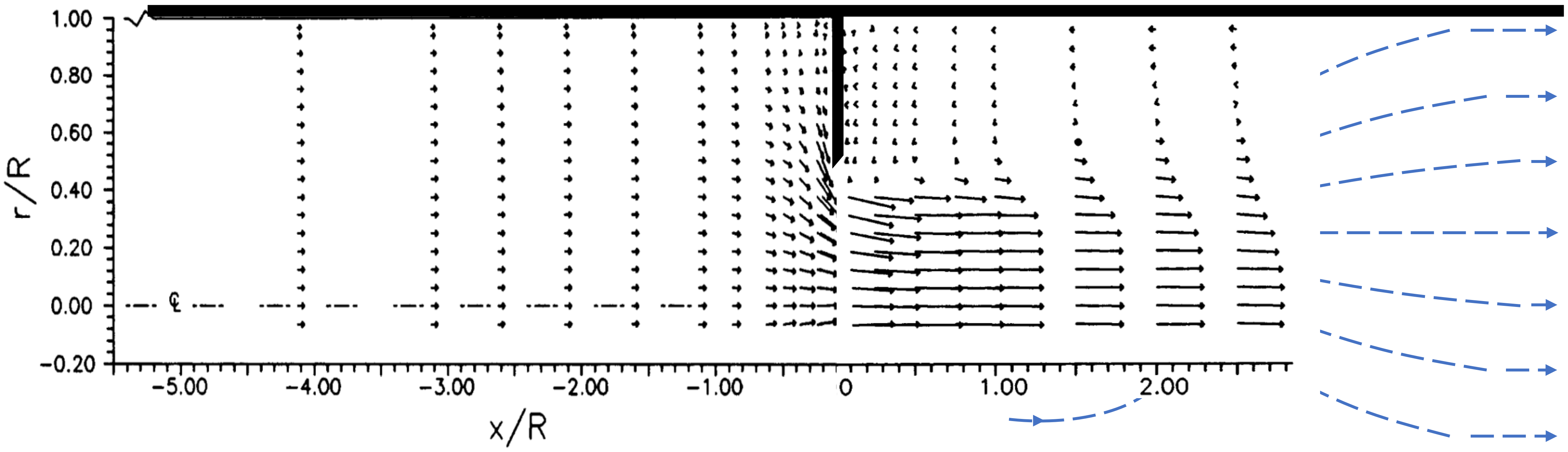
$$m_{trad} = C_D \frac{\pi d_o^2}{4} \sqrt{\frac{2\rho \Delta P_t}{1-\beta^4}}$$



Orifice

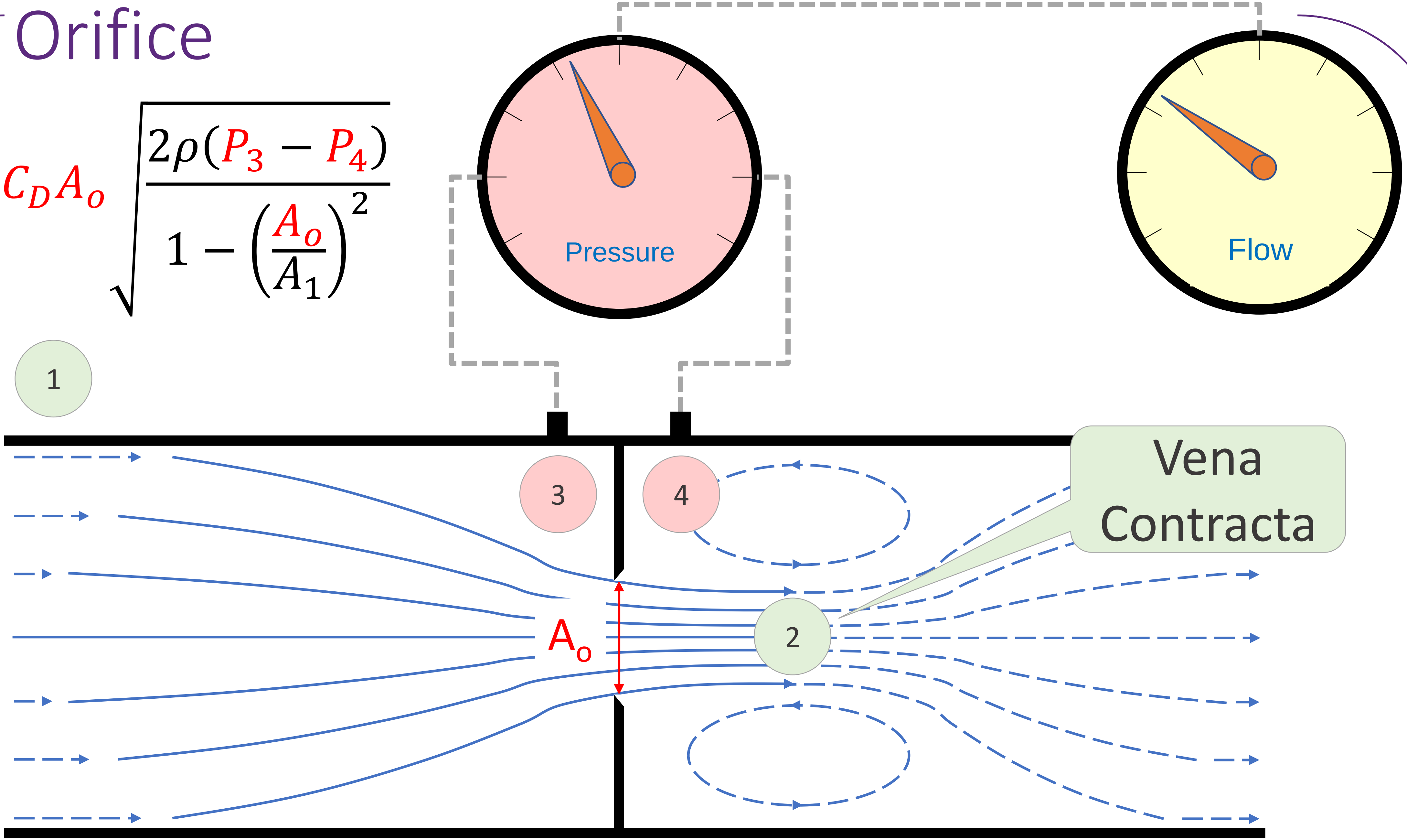
C_d~0.6

$$m_{trad} = C_D \frac{\pi d_o^2}{4} \sqrt{\frac{2\rho \Delta P_t}{1-\beta^4}}$$



Orifice

$$m = C_D A_o \sqrt{\frac{2\rho(P_3 - P_4)}{1 - \left(\frac{A_o}{A_1}\right)^2}}$$



Orifice

$$m = C_D A_o \sqrt{\frac{2\rho(P_3 - P_4)}{1 - \left(\frac{A_o}{A_1}\right)^2}}$$

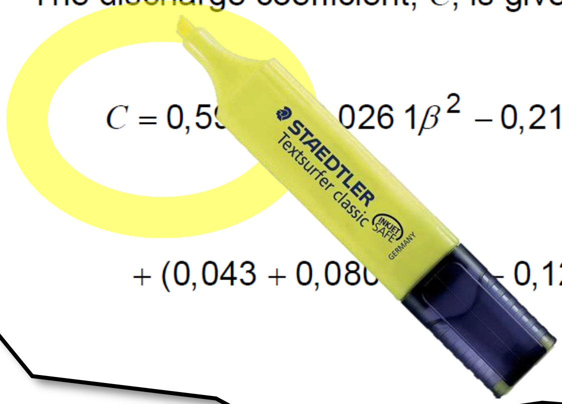
- C_D ~ 0.6, uncertainty ± 0.5%
- Uncertainty in mass flow (m) ~ ± 0.5 to 1%

5.3.2.1 Discharge coefficient, C

The discharge coefficient, C, is given by the Reader-Harris/Gallagher (1998) equation [5]:

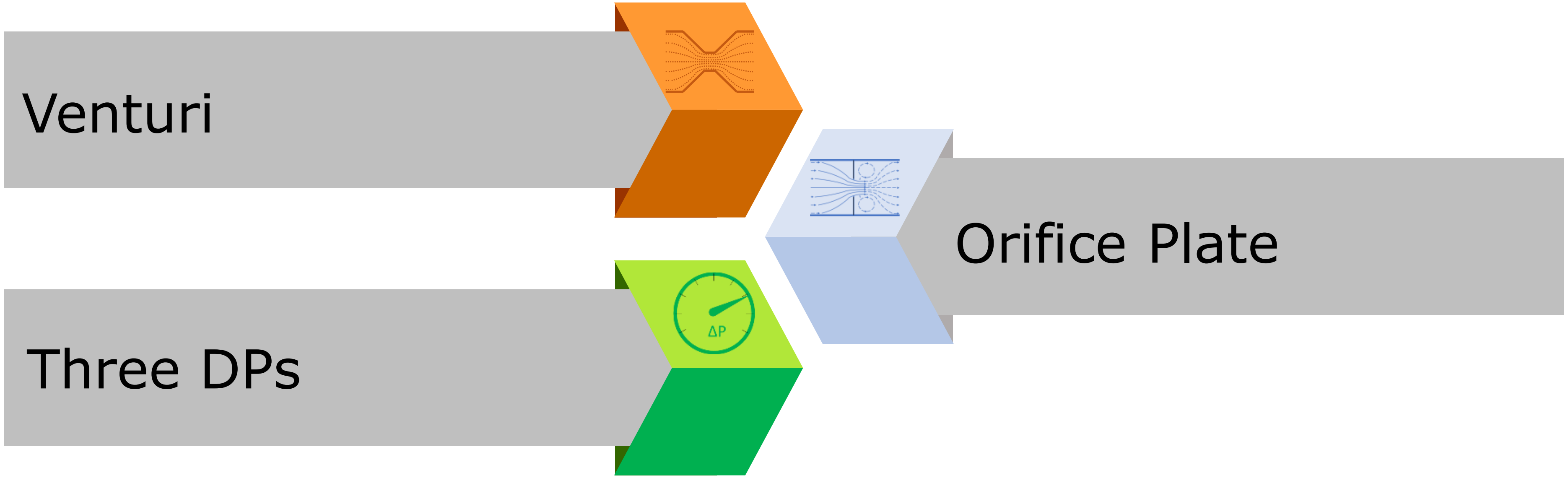
$$C = 0{,}59\text{[illegible]}026\,1\beta^2 - 0{,}216\beta^8 + 0{,}000\,521\left(\frac{10^6\beta}{Re_D}\right)^{0{,}7} + (0{,}018\,8 + 0{,}006\,3A)\beta^{3{,}5}\left(\frac{10^6}{Re_D}\right)^{0{,}3}$$

$$+ (0{,}043 + 0{,}08\text{[illegible]} - 0{,}123e^{-7L_1})(1 - 0{,}11A)\frac{\beta^4}{1-\beta^4} - 0{,}031(M'_2 - 0{,}8M'^{1{,}1}_2)\beta^{1{,}3}$$

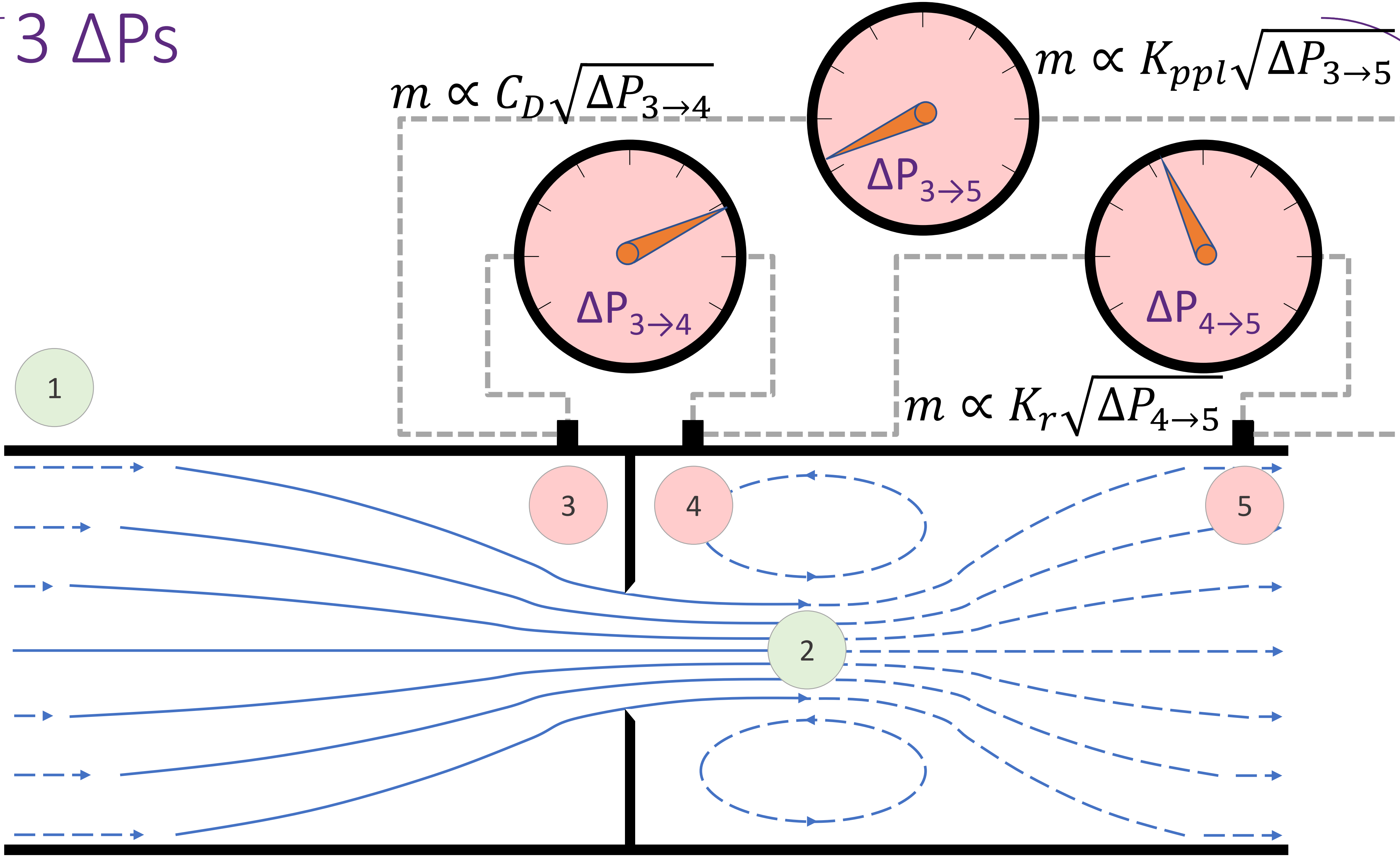


accord (e.s.i)

Agenda

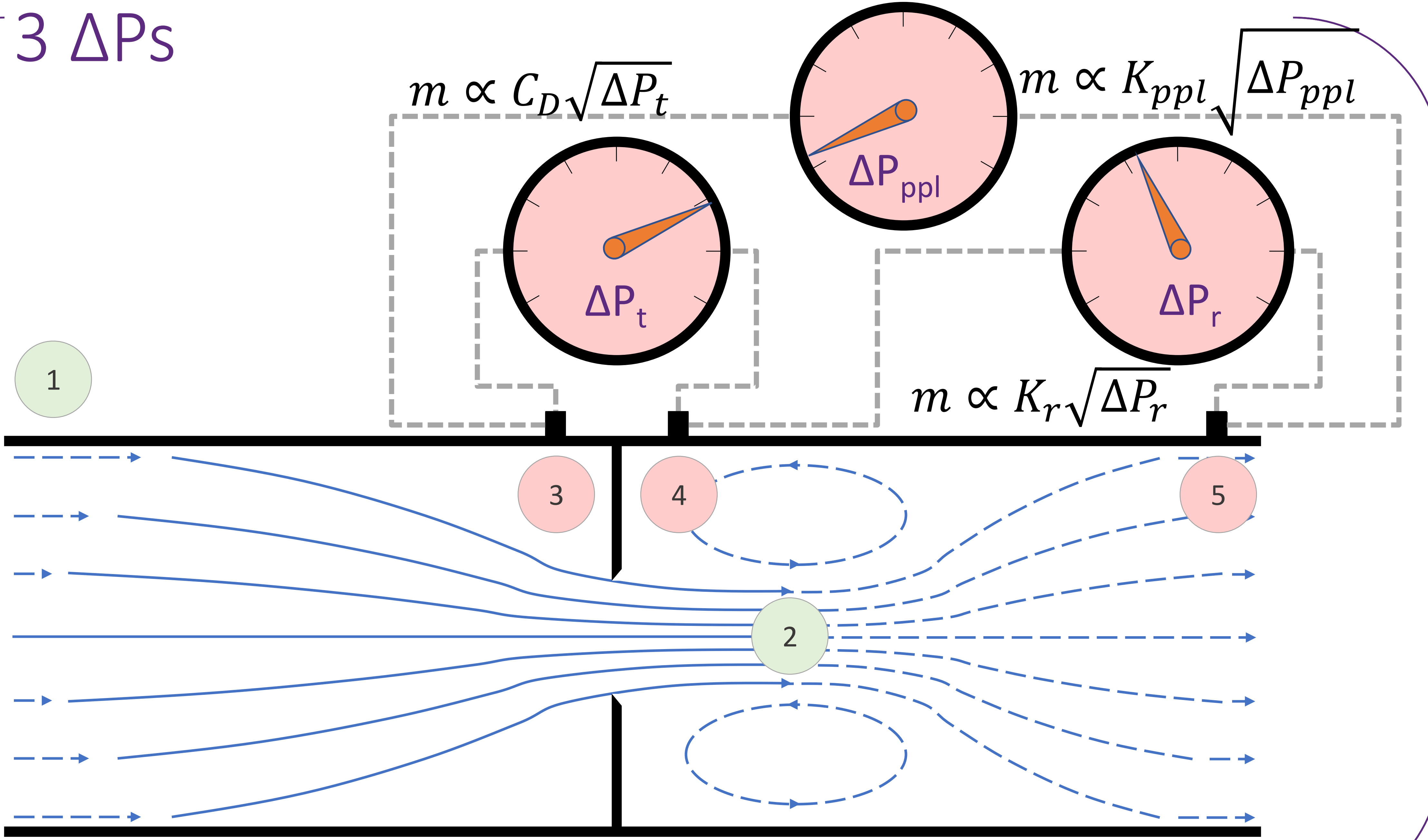


3 ΔPs



$m \propto C_D\sqrt{\Delta P_{3\to4}}$
$m \propto K_{ppl}\sqrt{\Delta P_{3\to5}}$
$m \propto K_r\sqrt{\Delta P_{4\to5}}$
ΔP3→4
ΔP3→5
ΔP4→5
1
2
3
4
5

3 ΔPs



$m \propto C_D \sqrt{\Delta P_t}$
$m \propto K_{ppl} \sqrt{\Delta P_{ppl}}$
$m \propto K_r \sqrt{\Delta P_r}$
ΔPt
ΔPppl
ΔPr
1
2
3
4
5

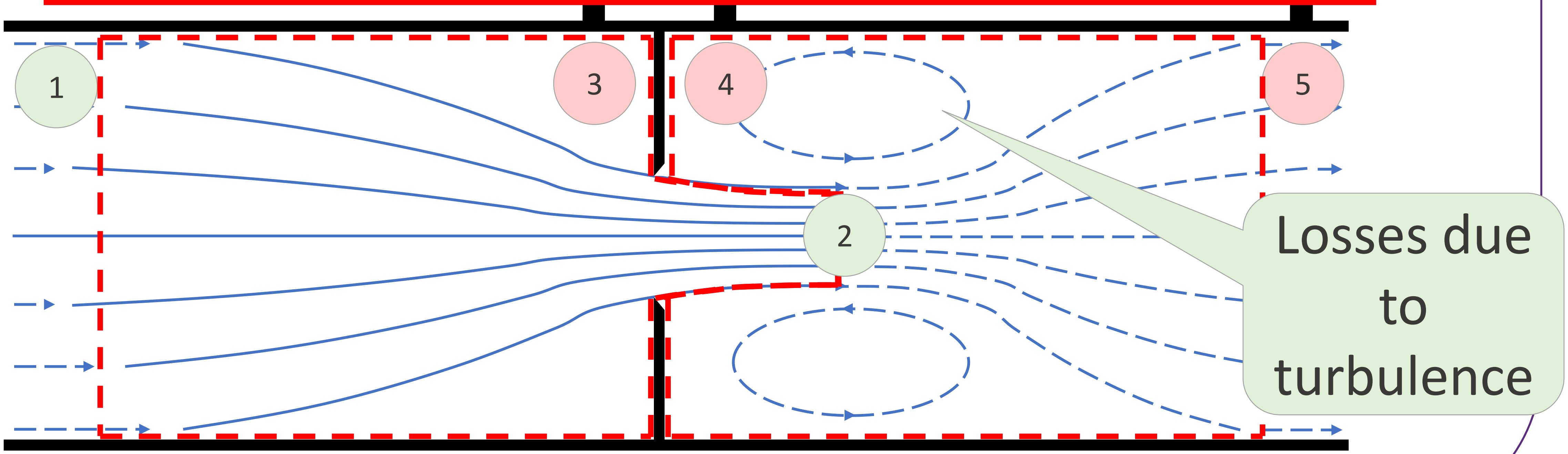
3 ΔPs

"Energy" Conservation (1→2)

Mass Conservation (1→2 →5)

Momentum Conservation (1→2)

Momentum Conservation (2→5)



3 ΔPs

$$P_1 + \frac{\rho V_1^2}{2} = P_2 + \frac{\rho V_2^2}{2} \qquad m = \rho V_1 A_1 = \rho V_2 A_2 = \rho V_5 A_5$$

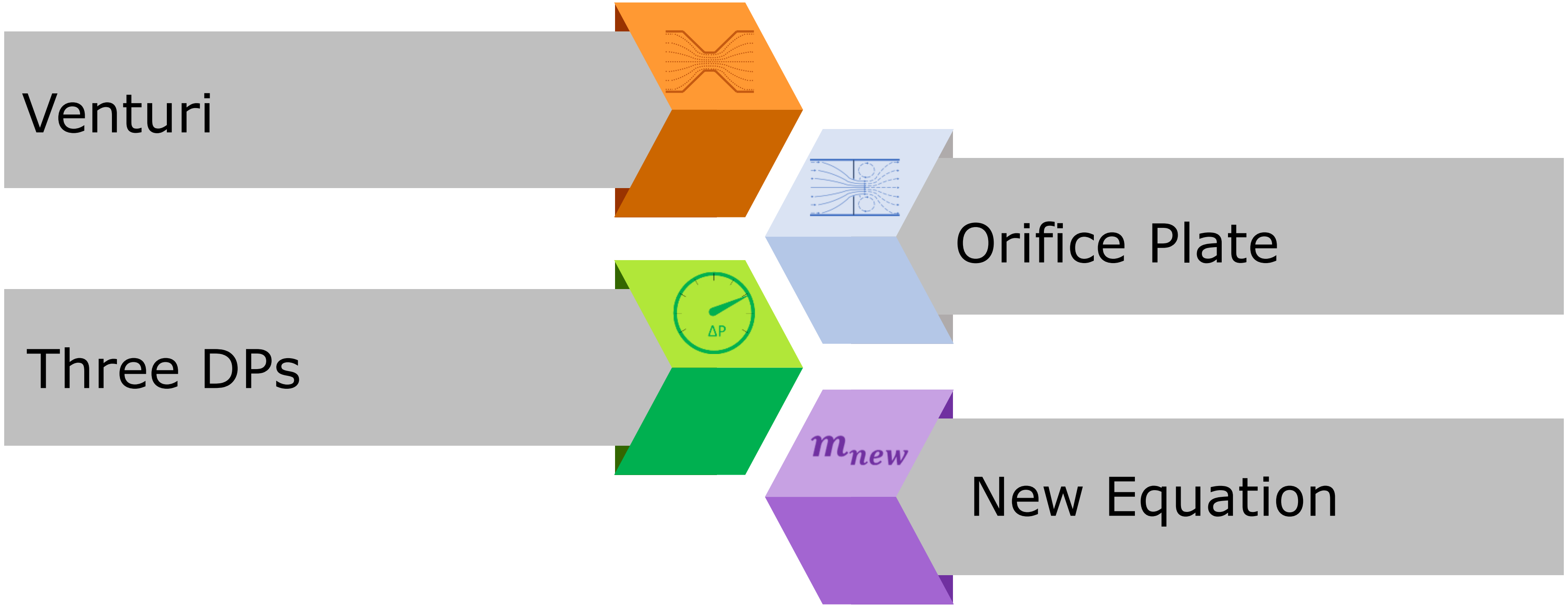
$$P_1 A_1 - (P_3(A_1 - A_o) + P_2 A_o) = m(V_1 - V_2)$$

$$A_1(P_2 - P_5) = m(V_1 - V_2)$$

$$m_{new} = \frac{A_1 \Delta P_{4\to5}}{\sqrt{\frac{2\left(1 - \left(\frac{A_o}{A_1}\right)\right)(\Delta P_{4\to5} + \Delta P_{3\to5})}{\rho}}}$$

accord (e.s.i)

Agenda



New Equation

$$m_{new} = \frac{A_1 \Delta P_{4\rightarrow 5}}{\sqrt{\frac{2\left(1-\left(\frac{A_o}{A_1}\right)\right)(\Delta P_{4\rightarrow 5} + \Delta P_{3\rightarrow 5})}{\rho}}}$$

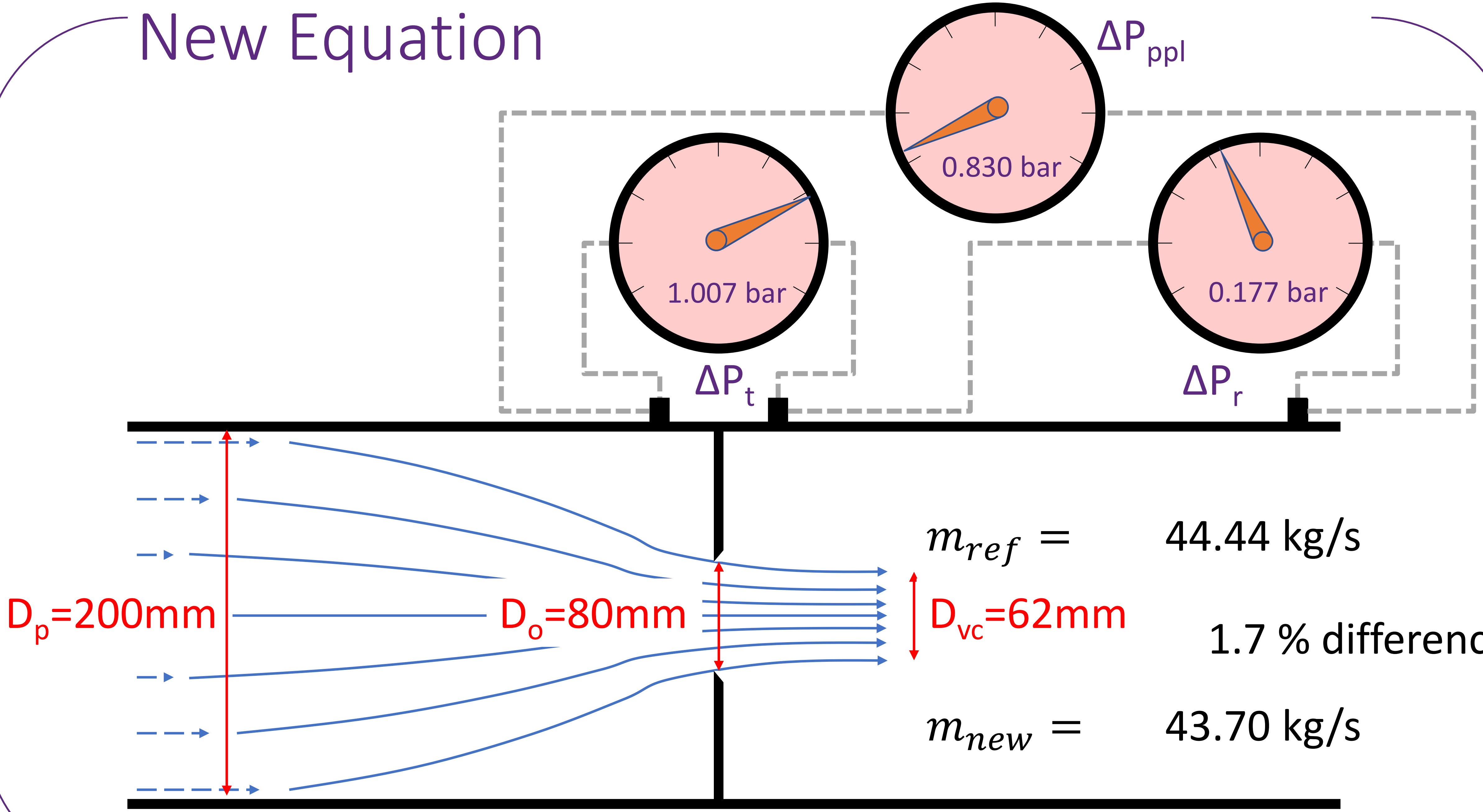
$$m_{trad} = C_D A_o \sqrt{\frac{2\rho(\Delta P_{3\rightarrow 4})}{1-\left(\frac{A_o}{A_1}\right)^2}}$$

New Equation

$$m_{new} = \frac{\pi d_o^2}{4\beta^2}\frac{\Delta P_r\sqrt{\rho}}{\sqrt{2(1-\beta^2)\left(\Delta P_r + \Delta P_{ppl}\right)}}$$

$$m_{trad} = C_D\,\frac{\pi d_o^2}{4}\sqrt{\frac{2\rho\Delta P_t}{1-\beta^4}}$$

New Equation



m_{ref} = 44.44 kg/s

1.7 % difference

m_{new} = 43.70 kg/s

Real Data, Water, 8” Pipe, 0.4 β

accord (e.s.l)

New Equation (with Losses)

$$P_1 + \frac{\rho V_1^2}{2} = P_2 + \frac{\rho V_2^2}{2}$$

$$m_{new} = \frac{\pi d_o^2}{4\beta^2} \frac{\Delta P_r \sqrt{\rho}}{\sqrt{2(1-\beta^2)\left(\Delta P_r + \Delta P_{ppl}\right)}}$$

New Equation (with Losses)

$$P_1 + \frac{\rho V_1^2}{2} = P_2 + \frac{\rho V_2^2}{2} + N\frac{\rho V_1^2}{2}$$

$$m_{new} = \rho \frac{\pi d_o^2}{4\beta^2}\sqrt{\frac{(1-\beta^2)(\Delta P_r + \Delta P_{ppl}) - \sqrt{\left((1-\beta^2)(\Delta P_r + \Delta P_{ppl})\right)^2 - \boldsymbol{N}\Delta P_r^2}}{\rho \boldsymbol{N}}}$$

New Equation (with Losses)

5.3.2.1 **Discharge coefficient,** C

$$m_{new} = \rho \frac{\pi d_o^2}{4\beta^2} \sqrt{\frac{(1-\beta^2)(\Delta P_r + \Delta P_{ppl}) - \sqrt{\left((1-\beta^2)(\Delta P_r + \Delta P_{ppl})\right)^2 - \mathbf{N}\Delta P_r^2}}{\rho \mathbf{N}}}$$

$$m_{trad} = C_D \frac{\pi d_o^2}{4} \sqrt{\frac{2\rho \Delta P_t}{1-\beta^4}}$$

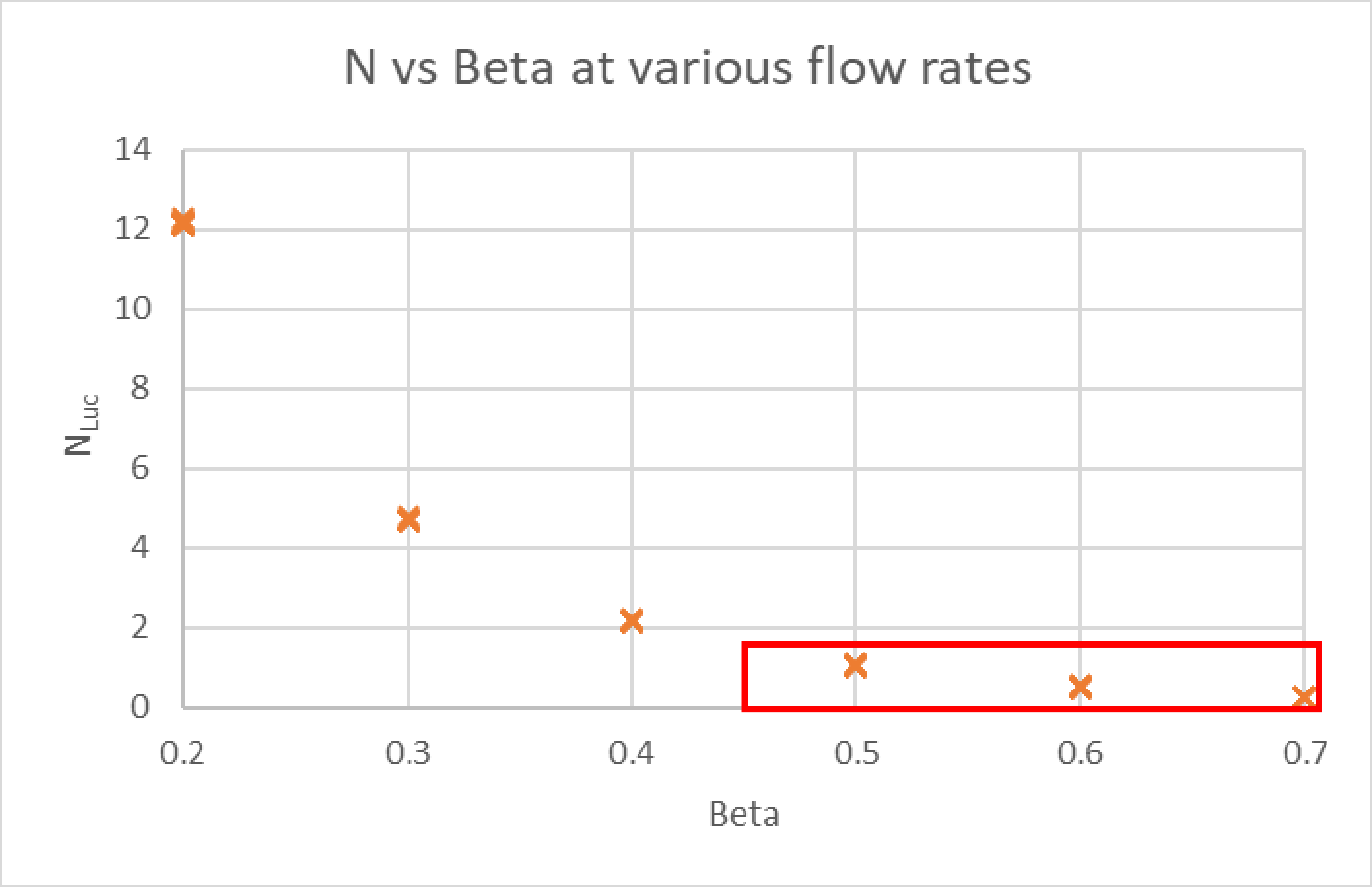
5.4 Pressure loss, $\Delta\varpi$

5.4.1 The pressure loss, $\Delta\varpi$, for the orifice plates desc
to the differential pressure Δp by Equation (7)

$$\Delta\varpi = \frac{\sqrt{1-\beta^4(1-C^2)} - C\beta^2}{\sqrt{1-\beta^4(1-C^2)} + C\beta^2}\Delta p$$

accord (e.s.i)

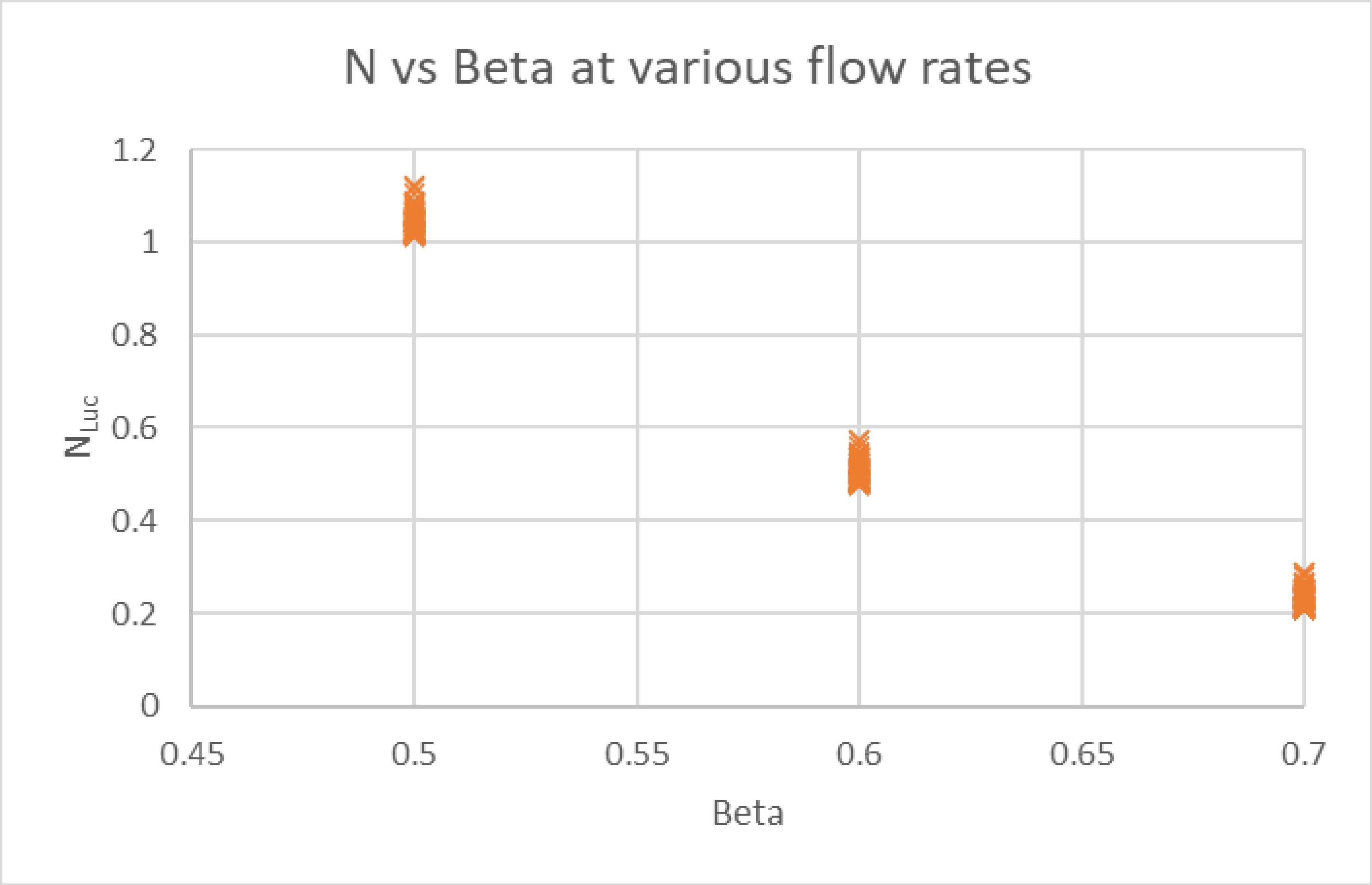
New Equation (with Losses)



New Equation (with Losses)

New Equation (with Losses)

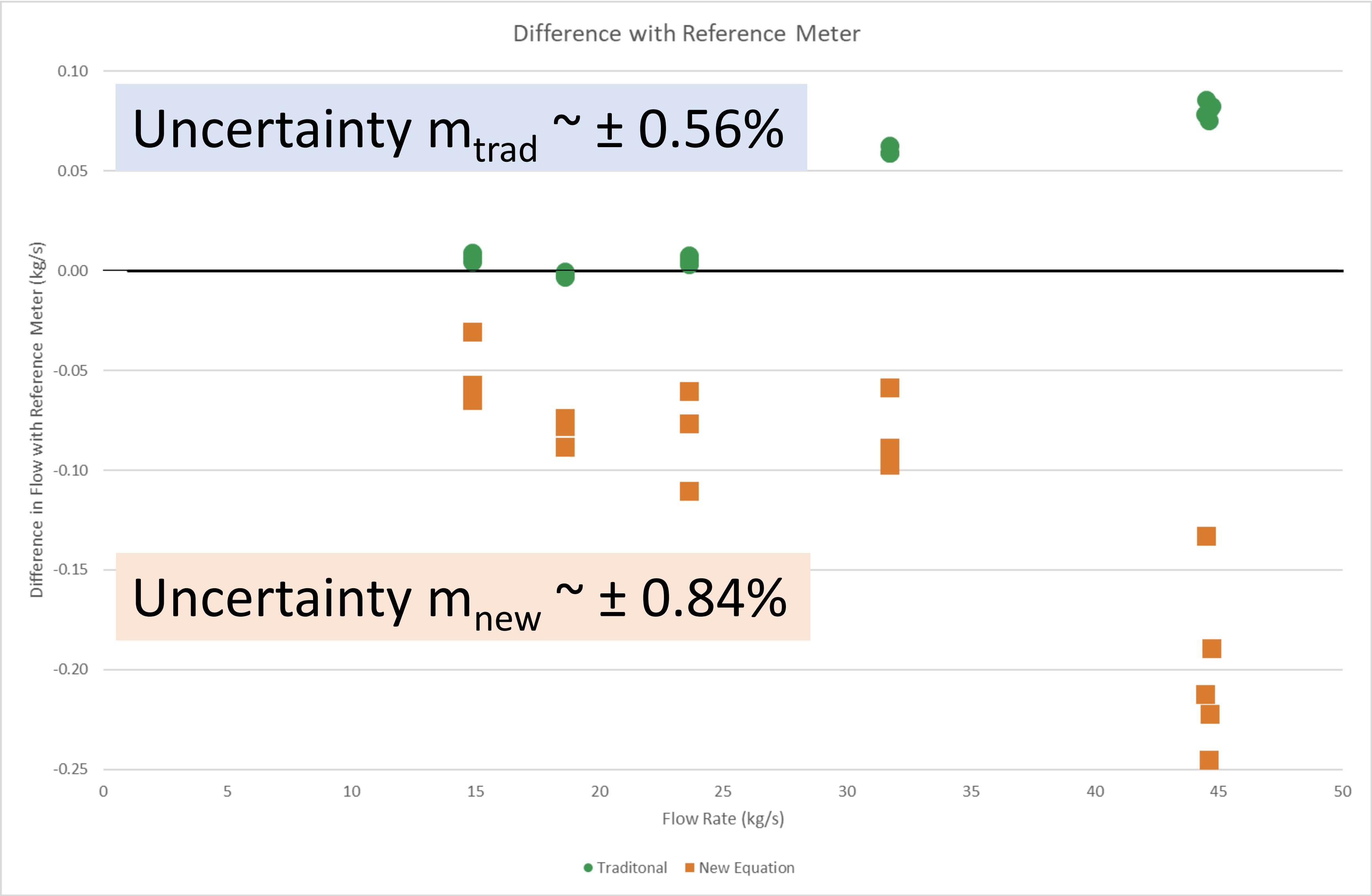
New Equation (with Losses)



Agenda


Venturi
Orifice Plate
Three DPs
ΔP
m_{new}
New Equation
Does it work?

Real Data



Real Data, Water, 8" Pipe, 0.4 β

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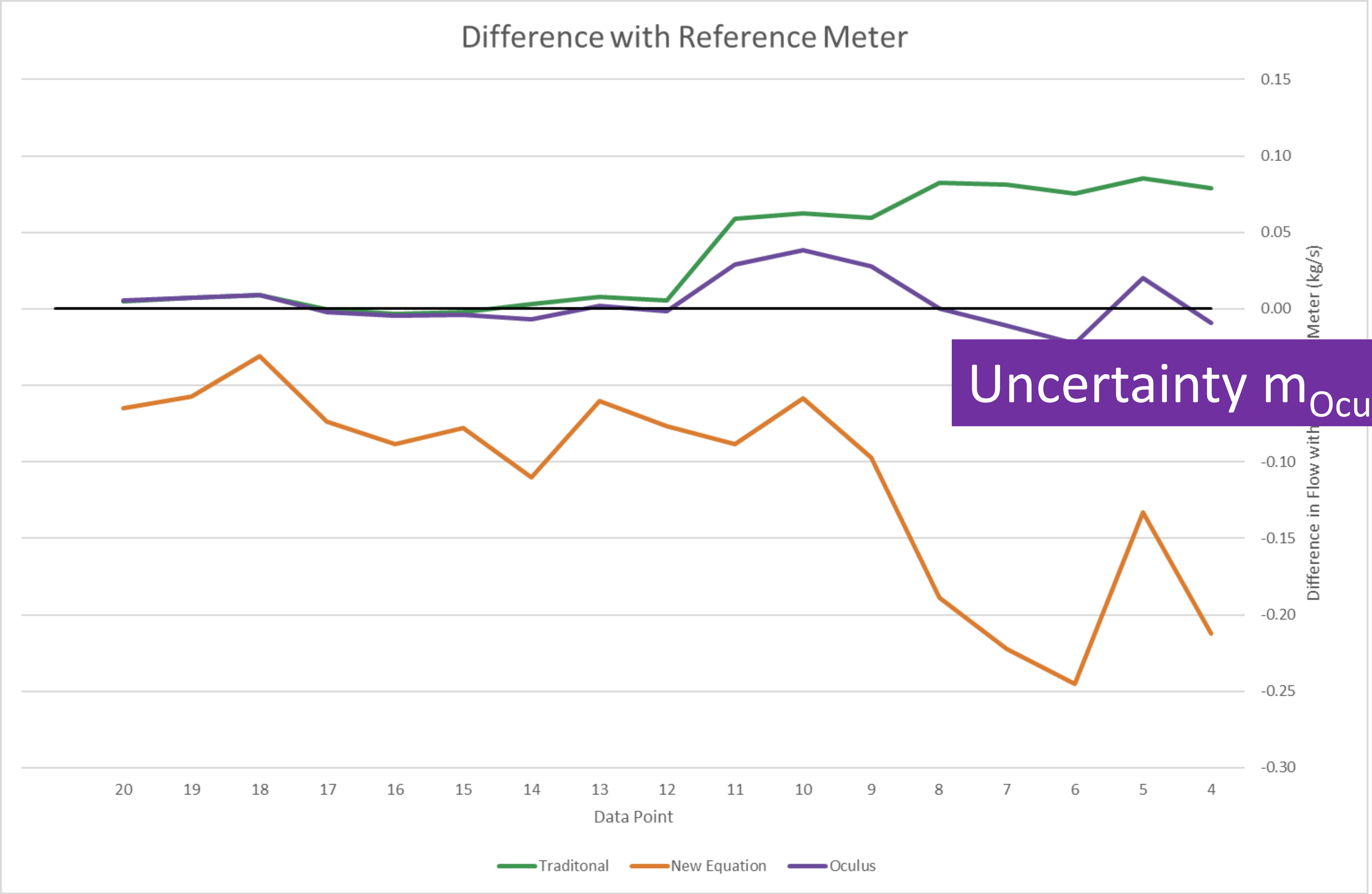
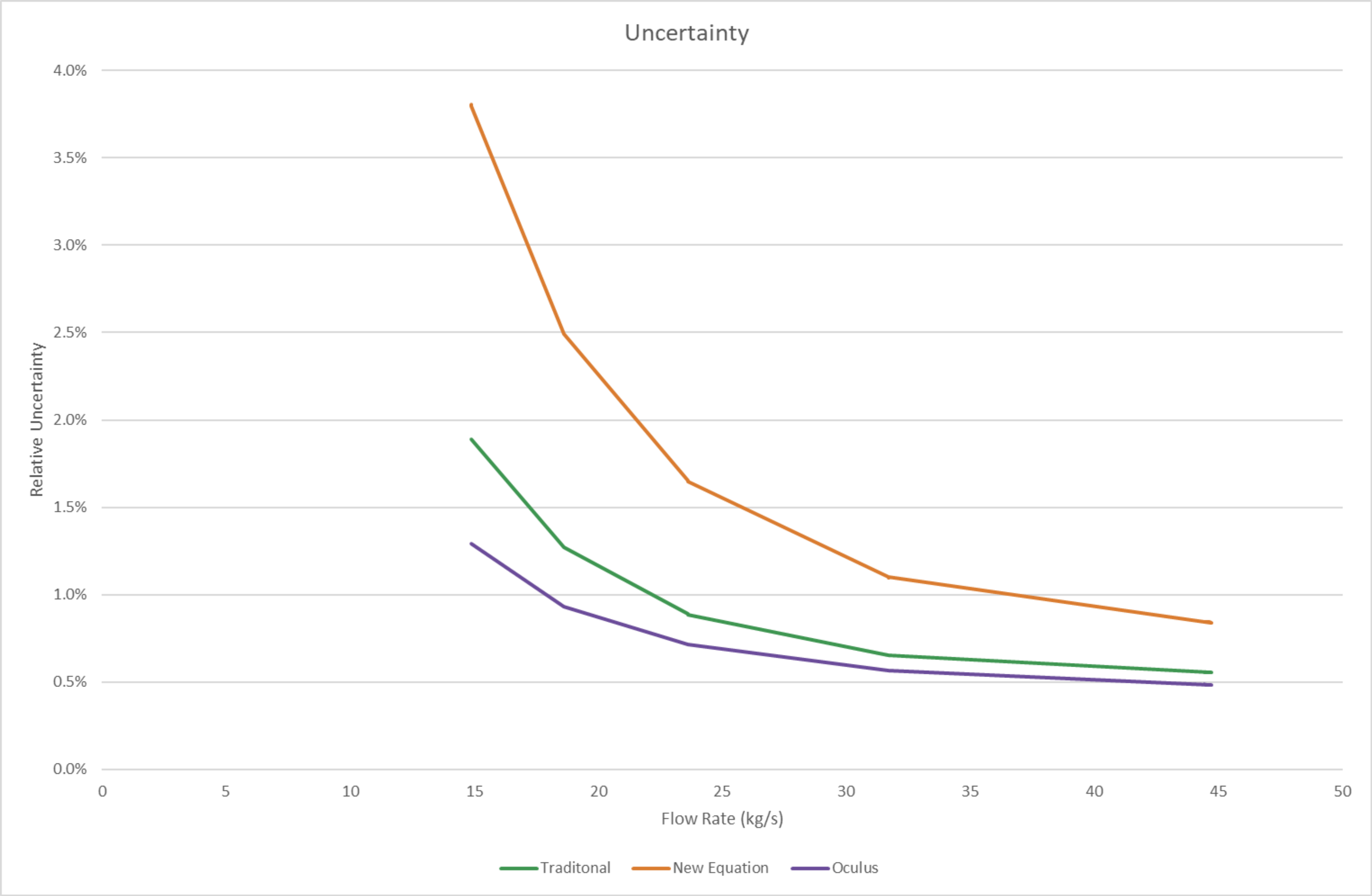
Real Data



Uncertainty m_{Oculus} ~ ± 0.49%

Real Data, Water, 8” Pipe, 0.4 β

Real Data



Real Data, Water, 8” Pipe, 0.4 β

Conclusions

- New Equation
- Desktop Exercise
- Redundancy
- m_{new} Reduces Uncertainty
- Extends Range
- Reduces Costs