Calibration of A V-Cone for Low Mass Flows For Small Core Compressor Research

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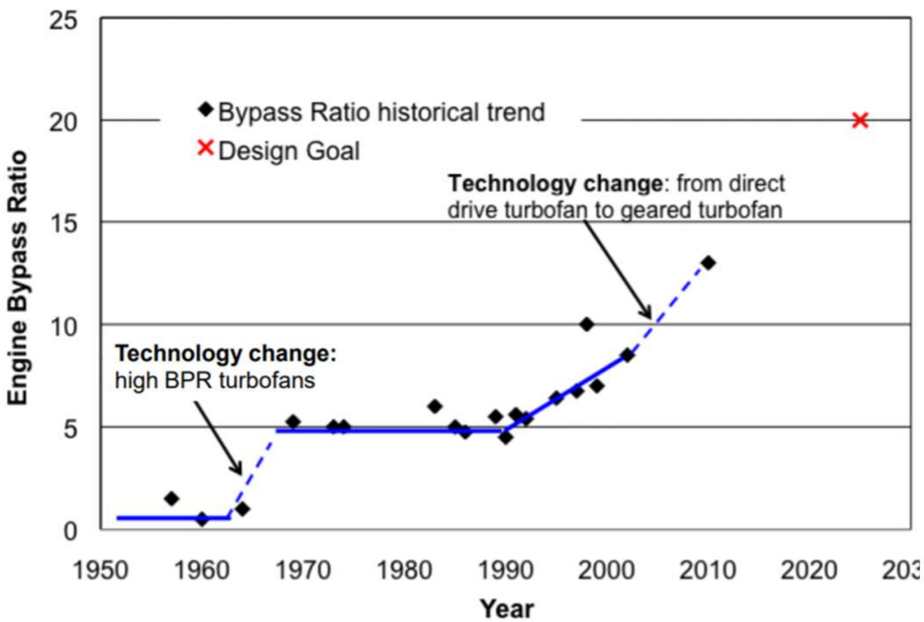
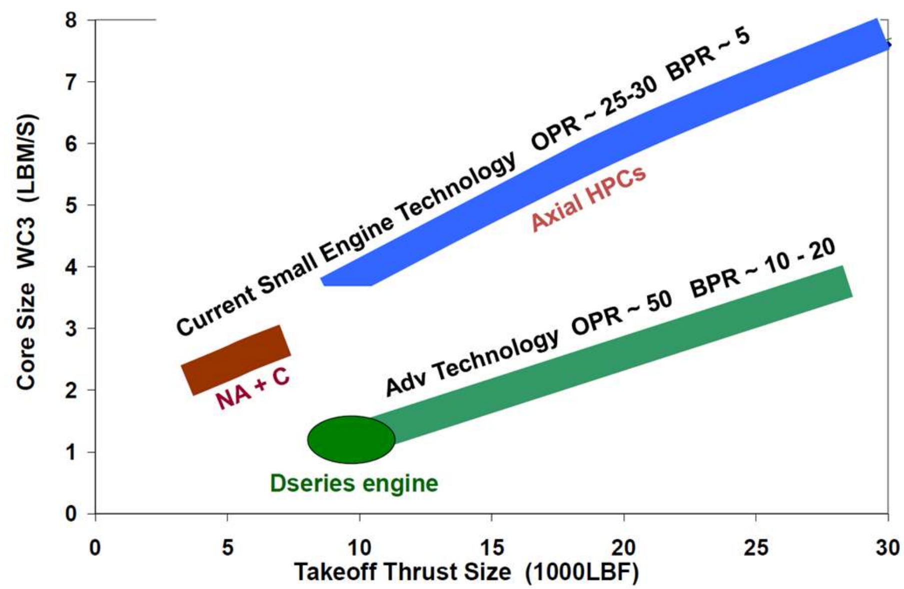
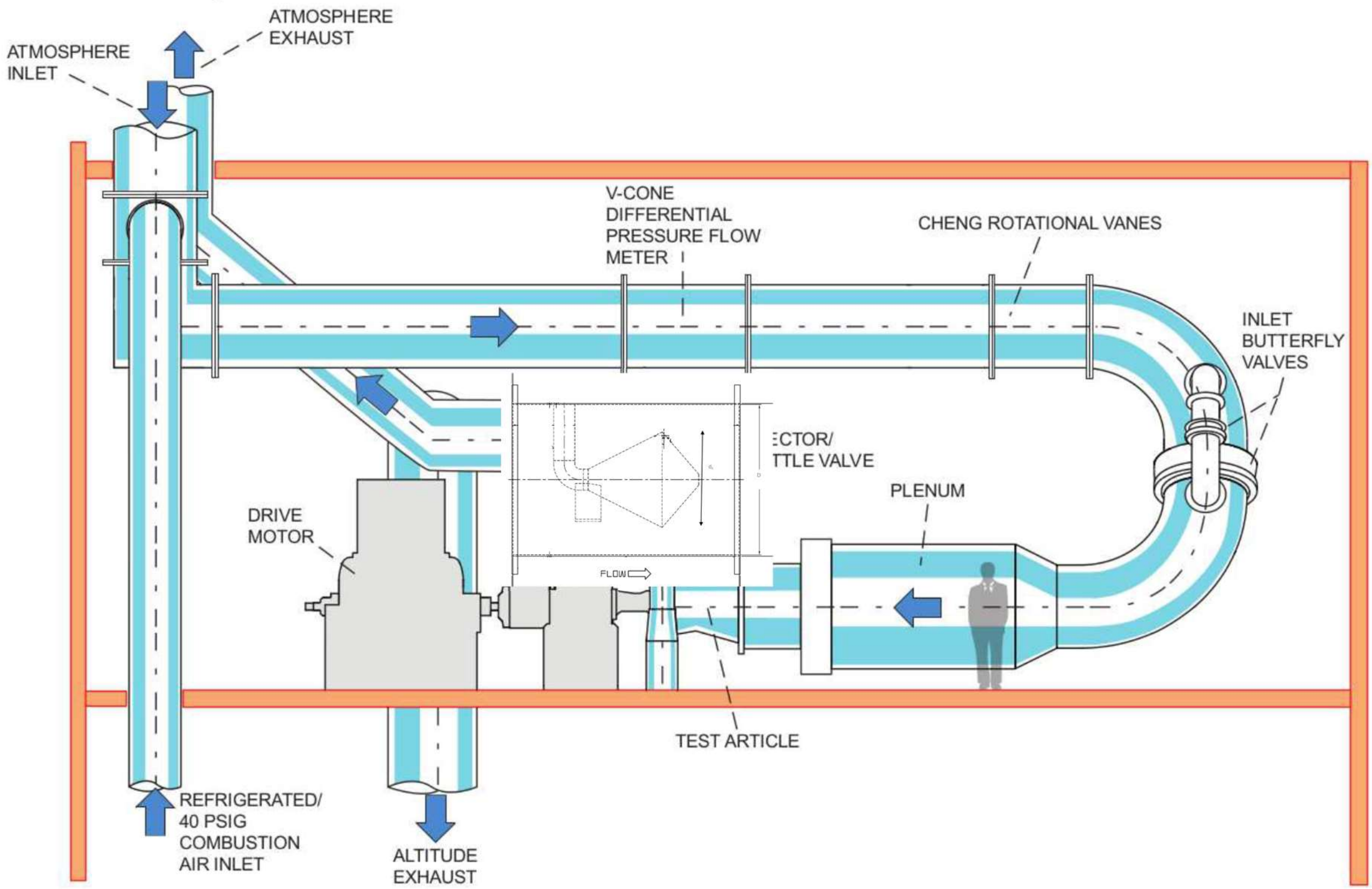
Motivation



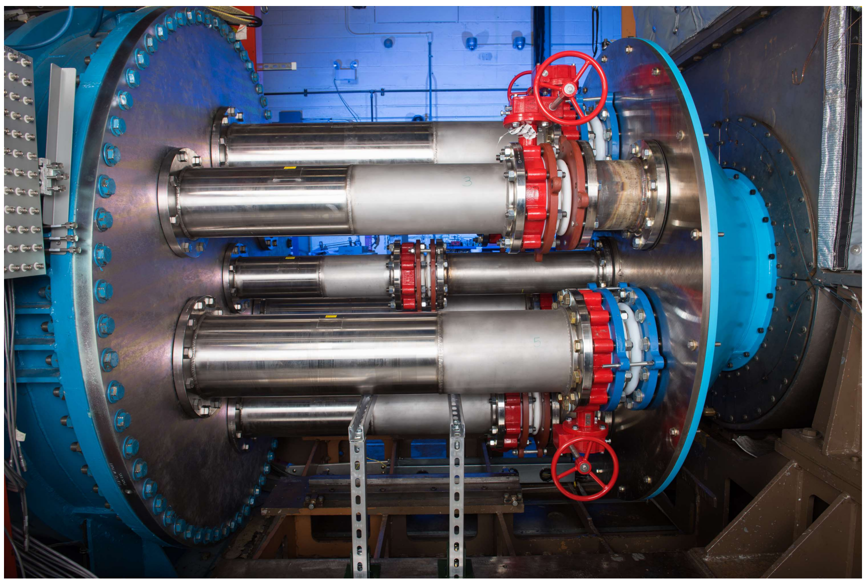


- Charts from NASA CR2010-216794/Vol1, 2010
- Ballal, D.R. and Zelina, J., “Progress in Aeroengine Technology (1939 – 2003)” *Journal of Aircraft,* 41(1), 2004

Multistage Axial Compressor Facility ("W-7")



Sonic Nozzles



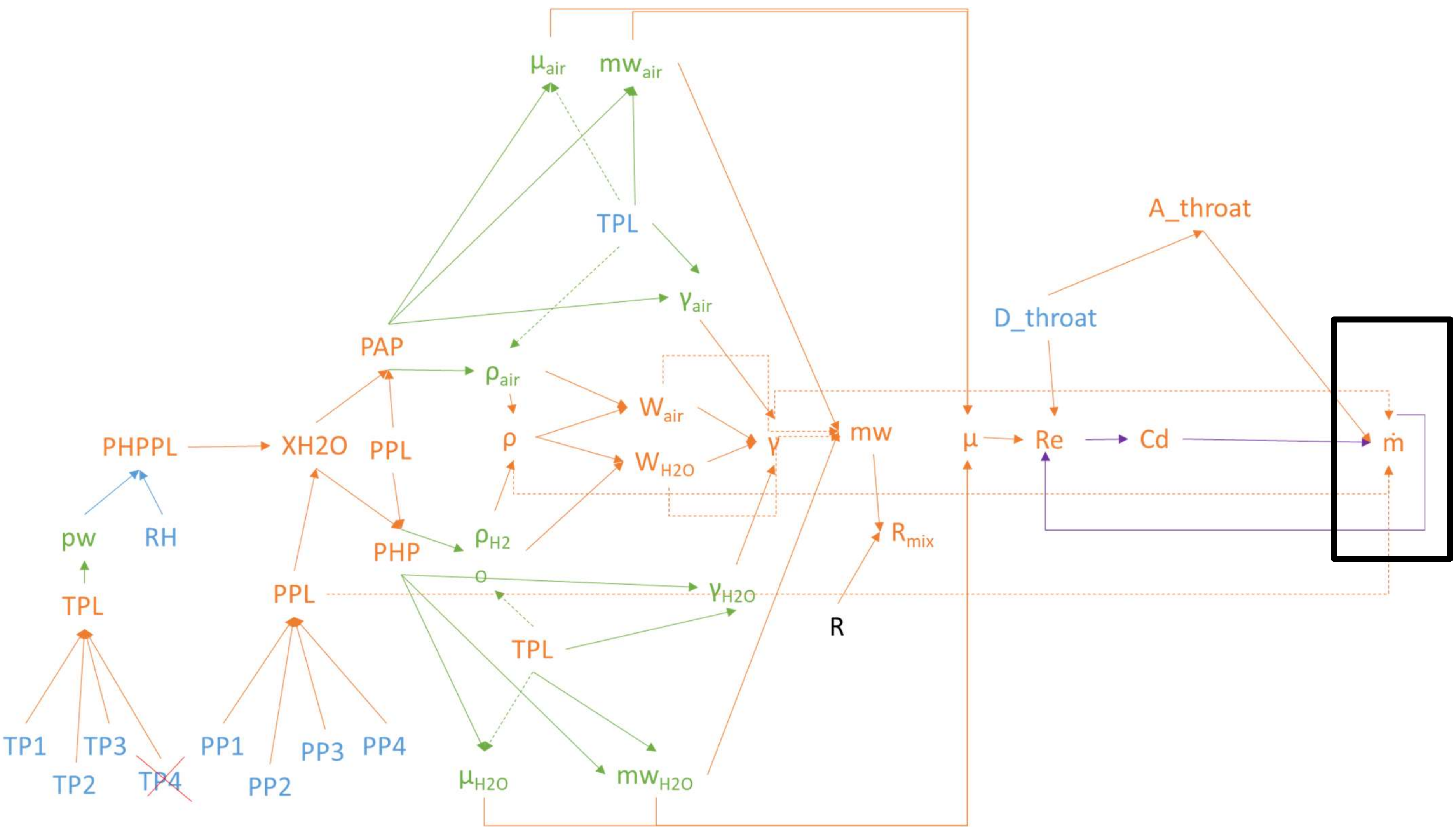
ASME MFC-7-2016, 2016

$$C_d = 0.9959 - 2.720 Re^{-1/2}$$

$$Re = \frac{4\dot{m}}{\pi \mu D}$$

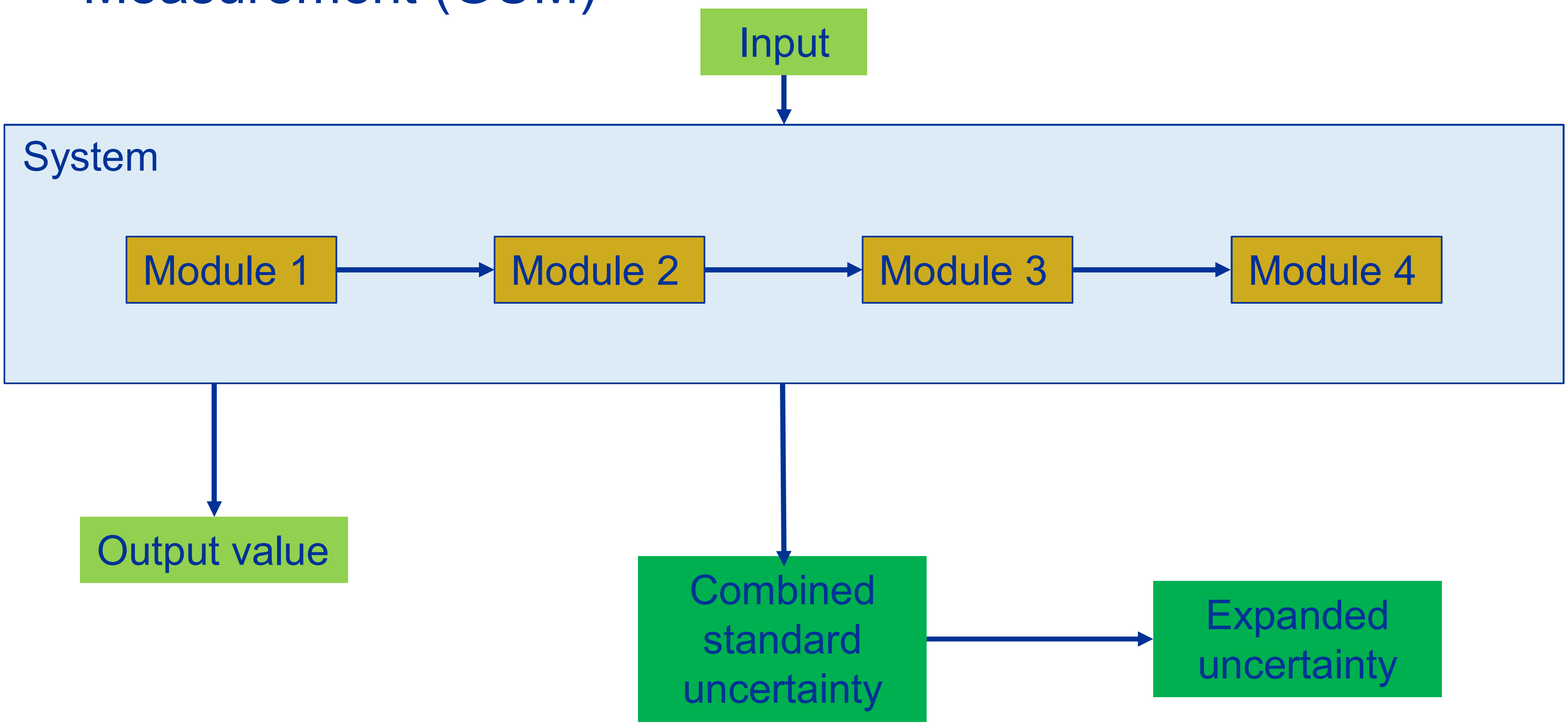
$$C_R = \frac{\rho c \sqrt{R T_0}}{P_0 \sqrt{M}}$$

$$\dot{m} = C_d A \sqrt{\gamma} \left(\frac{2}{\gamma + 1} \right)^{\frac{\gamma+1}{\gamma-1}} P_0 \rho$$

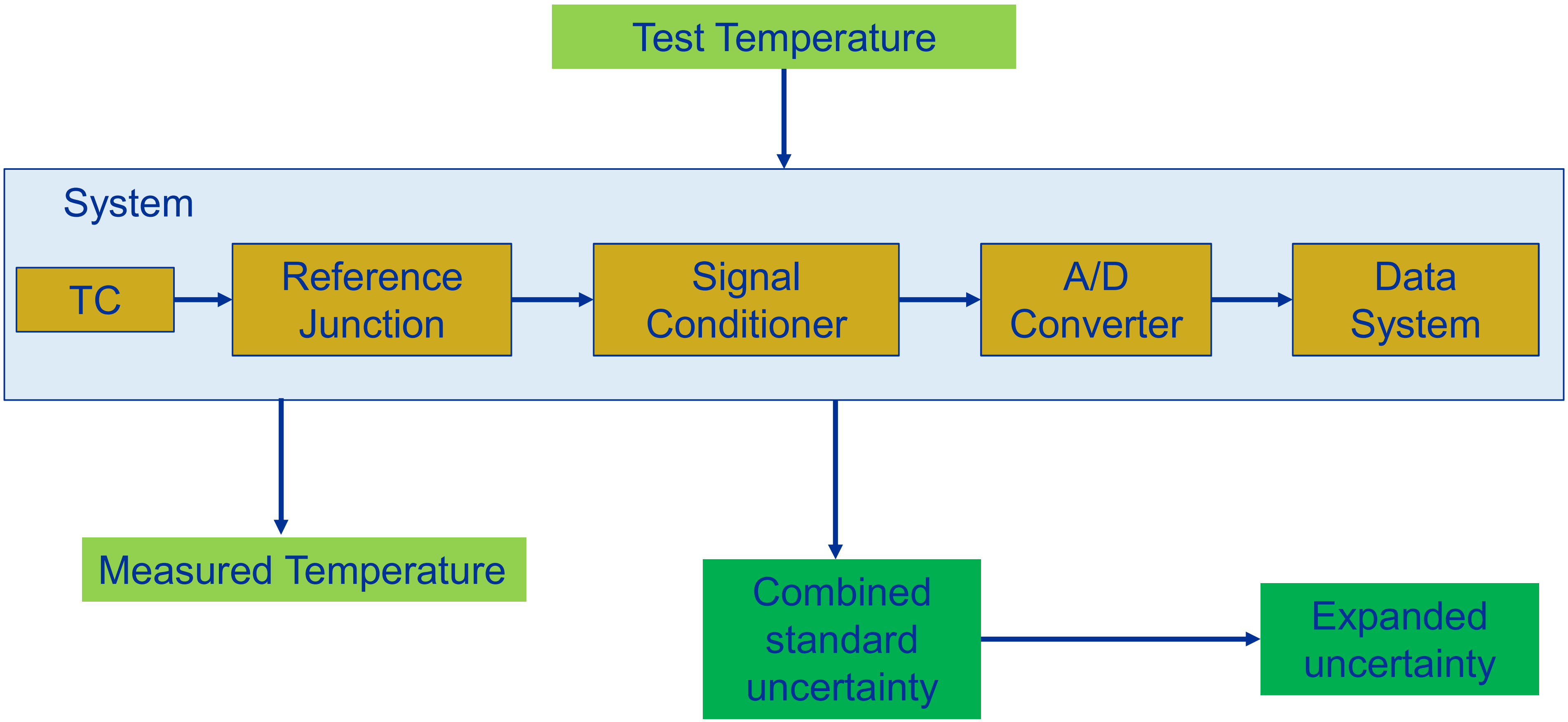

μair
mwair
TPL
A_throat
γair
D_throat
PAP
ρair
Wair
PHPPL
XH2O
PPL
ρ
γ
mw
μ
Re
Cd
ṁ
WH2O
pw
RH
ρH2
Rmix
PHP
γH2O
TPL
PPL
R
TPL
TP1
TP3
PP1
PP3
PP4
TP2
TP4
PP2
μH2O
mwH2O

MANTUS

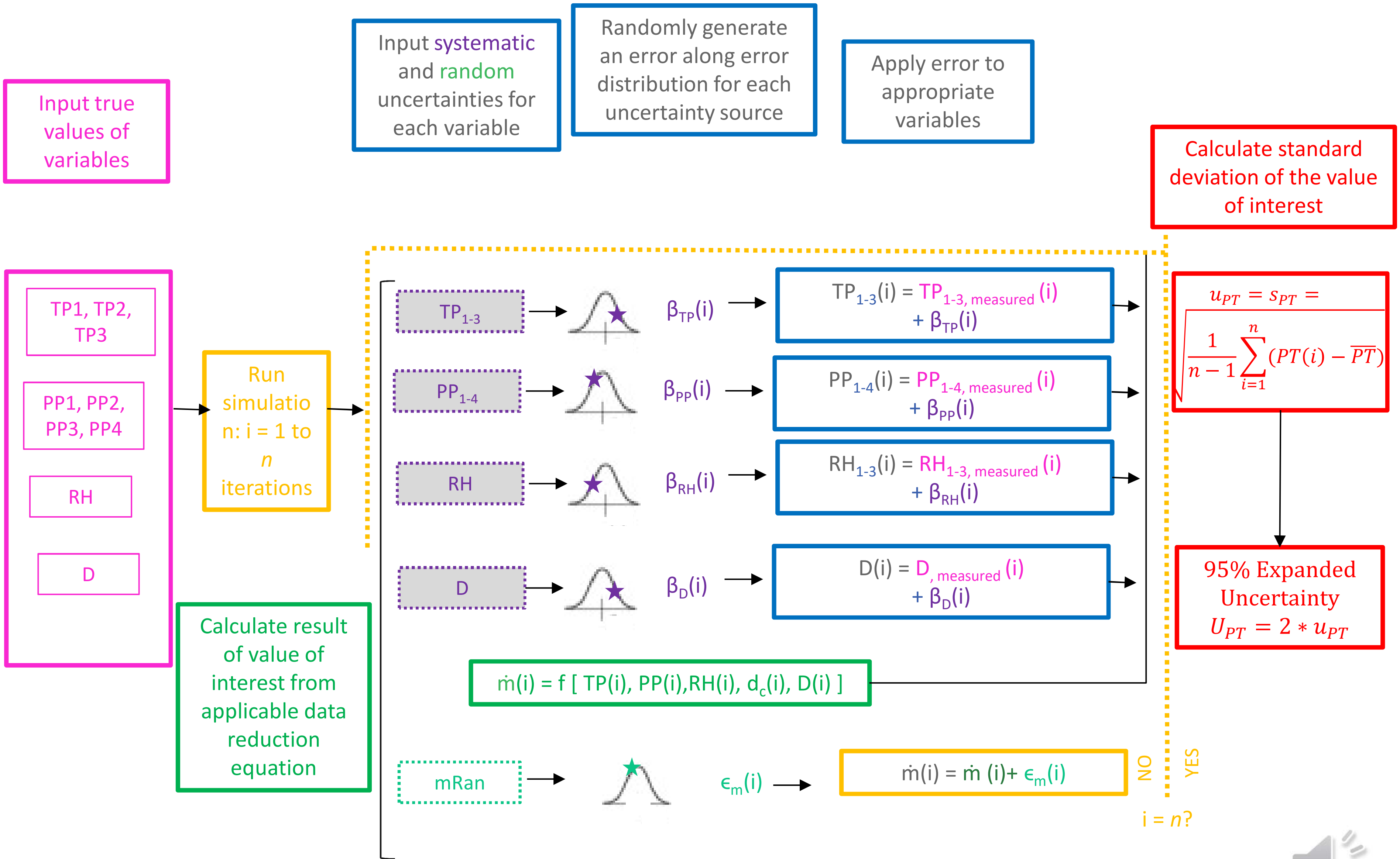
- Spreadsheet based
- ISO Guide to the Expression of Uncertainty in Measurement (GUM)*



*JCGM 100:2008 Evaluation of Measurement Data – Guide to the Expression of Uncertainty in Measurement


Test Temperature
System
TC
Reference Junction
Signal Conditioner
A/D Converter
Data System
Measured Temperature
Combined standard uncertainty
Expanded uncertainty

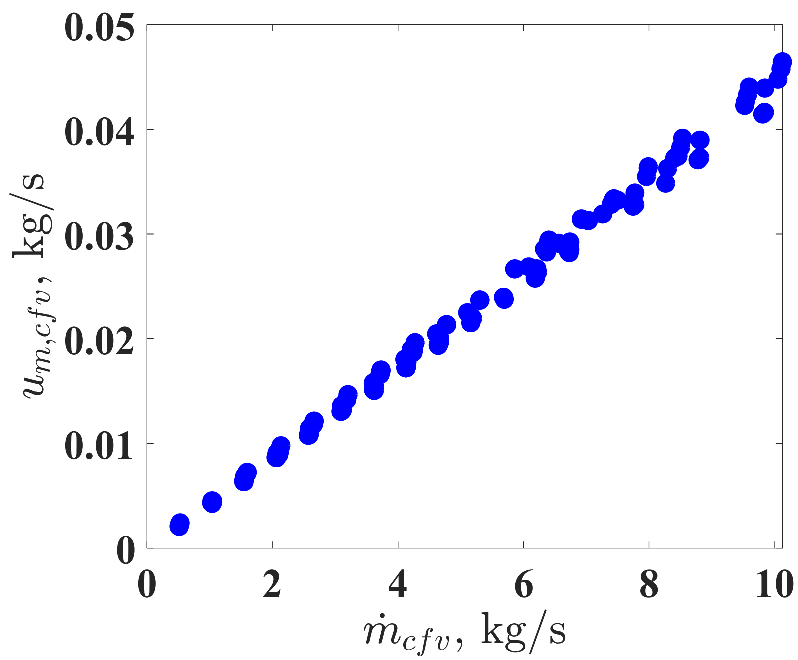
Monte Carlo Analysis



* Coleman, Steele: Experimentation, Validation, and Uncertainty Analysis For Engineers; above chart based on Figure 3.4, pg.72.

Uncertainty in $\dot{m}_{cfv}$

Measured Variable	Uncertainty
P_0	0.023%
T_0	0.23 – 0.3%
RH	1%
D	0.024-0.048%
C_d	0.03%
Repeatability	0.0003 – 0.016%

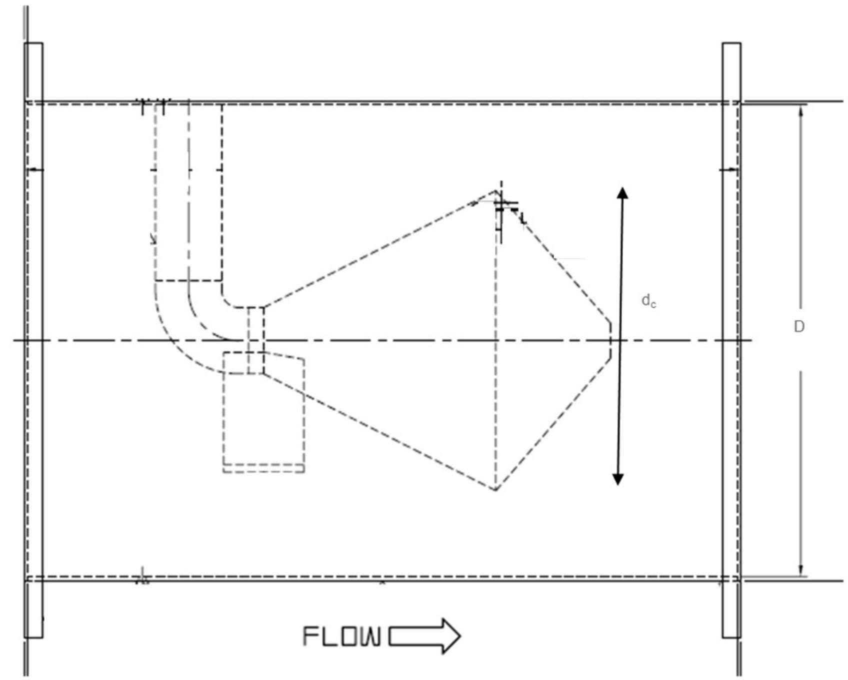


V-Cone

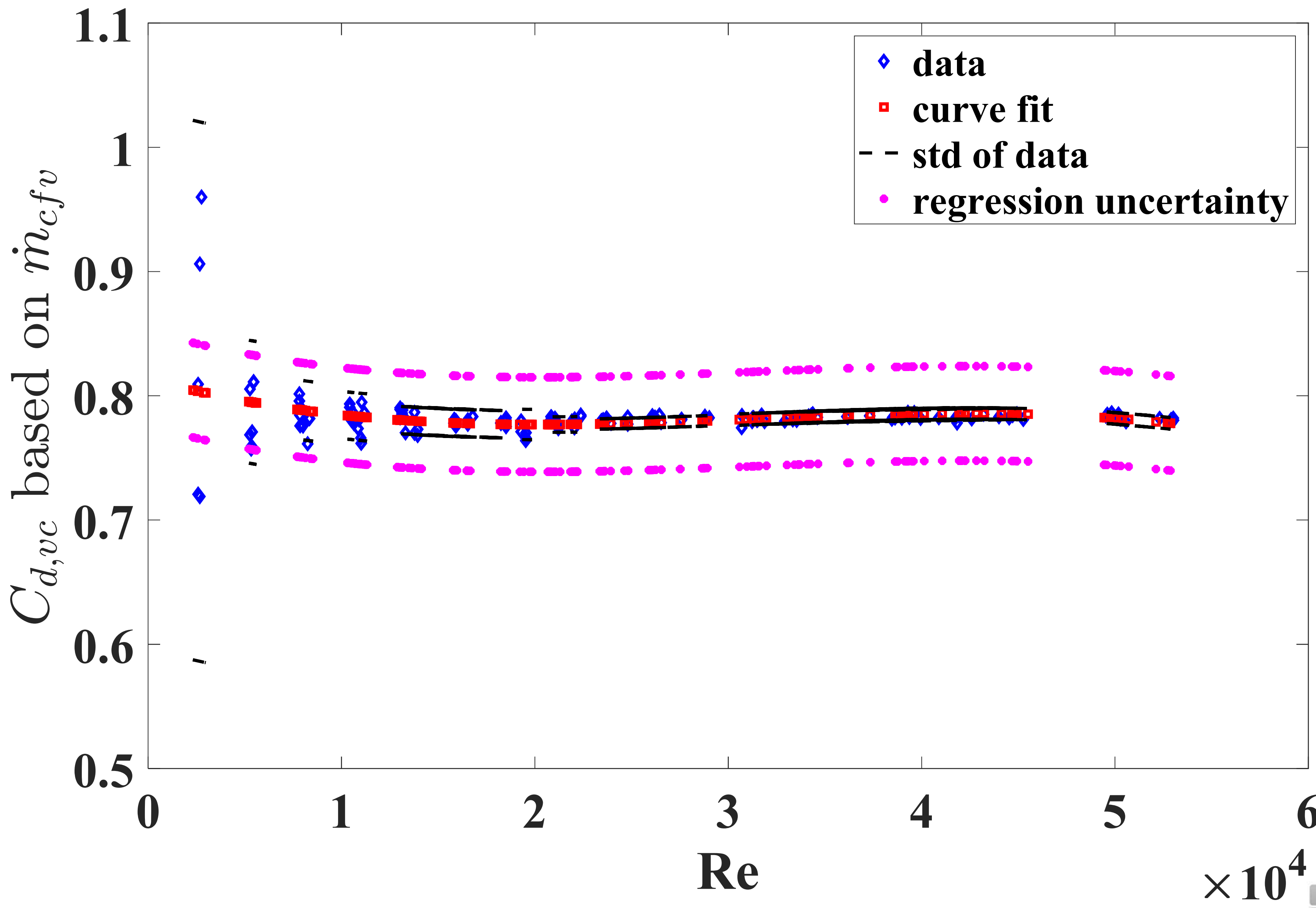
- $\beta = \sqrt{1 - \frac{d_c^2}{D}}$
- $y = 1 - (0.649 + 0.696\beta^4)\frac{\Delta P}{\gamma P_0}$
- $\dot{m} = C_d \left(\frac{\pi}{48}(D^2 - d_c^2)\right) y \sqrt{\frac{2 g_c \Delta P \rho}{1-\beta^4}}$

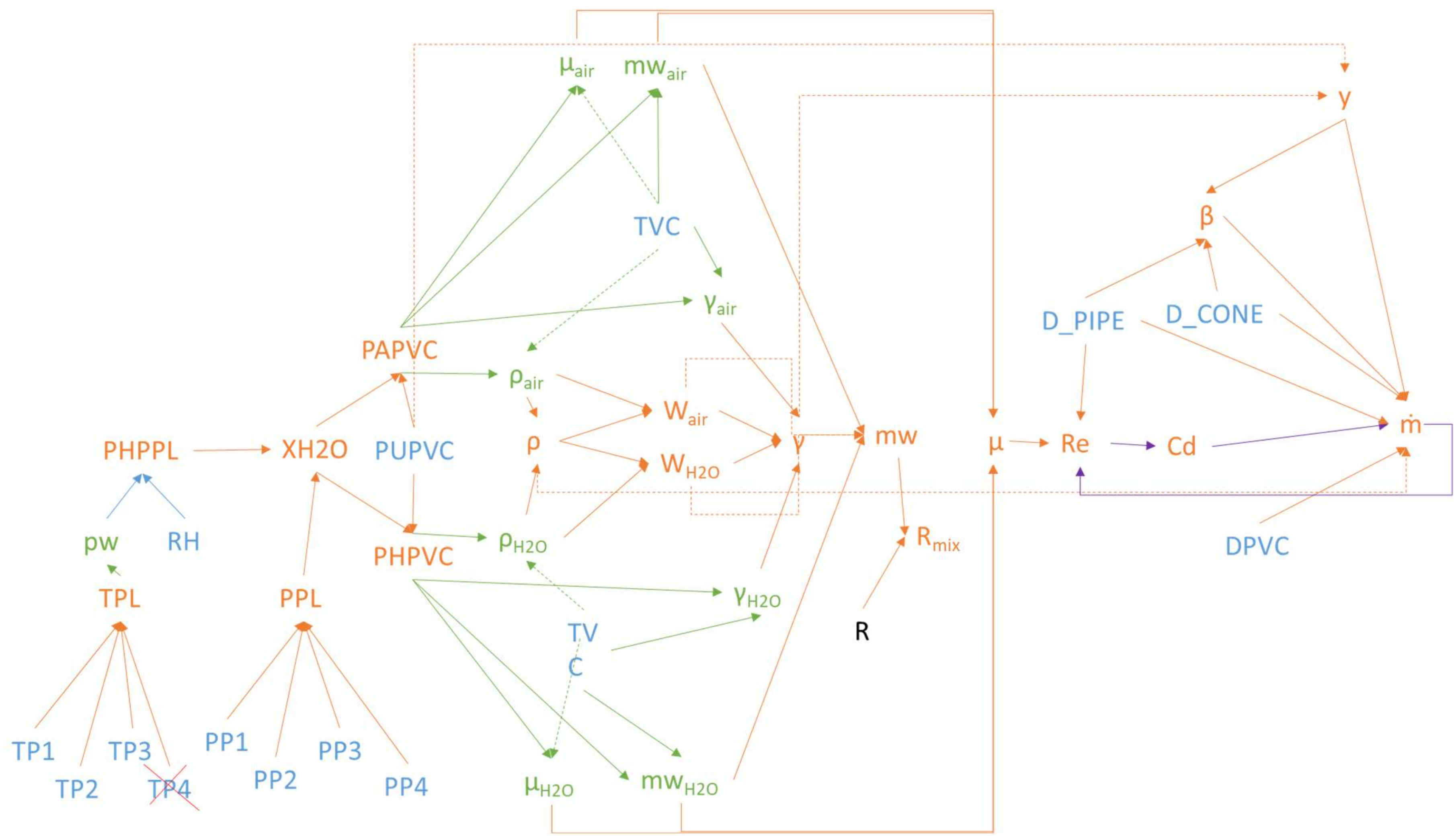
$$C_d = \frac{\dot{m}}{\left(\frac{\pi}{48}(D^2 - d_c^2)\right) y \sqrt{\frac{2 g_c \Delta P \rho}{1 - \beta^4}}}$$

$$C_d = aRe^3 + bRe^2 + cRe + d$$



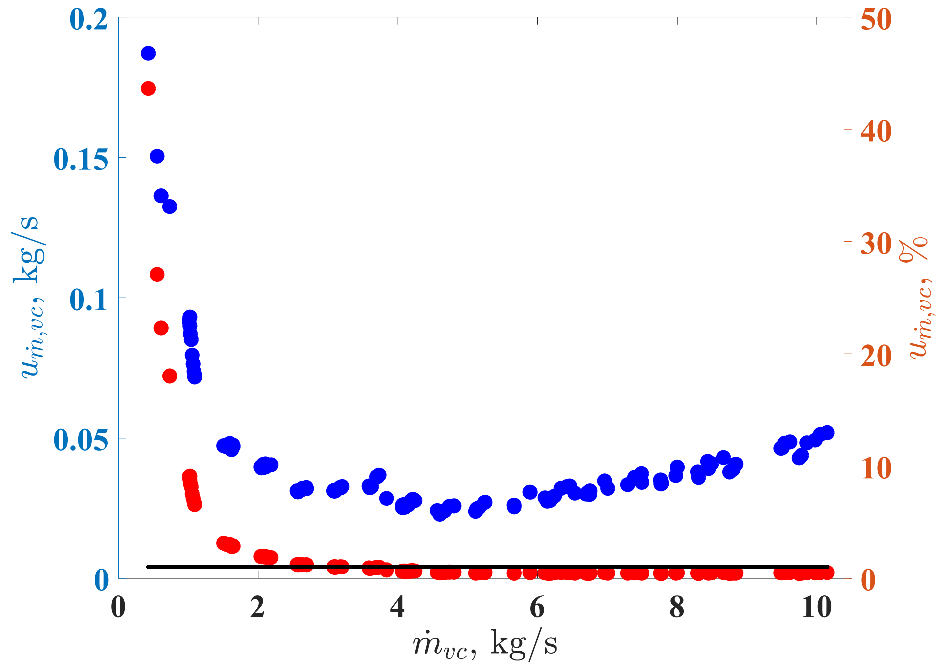
ISO5167-5:2016(E) 2016


data
curve fit
std of data
regression uncertainty
$C_{d,vc}$ based on $\dot{m}_{cfv}$
Re
$\times 10^4$
0.5
0.6
0.7
0.8
0.9
1
1.1
0
1
2
3
4
5
6


μair
mwair
y
TVC
β
γair
D_PIPE
D_CONE
PAPVC
ρair
Wair
ρ
γ
mw
μ
Re
Cd
ṁ
PHPPL
XH2O
PUPVC
WH2O
pw
RH
ρH2O
Rmix
DPVC
PHPVC
TPL
PPL
γH2O
TV
C
R
TP1
TP3
PP1
PP3
TP2
TP4
PP2
PP4
μH2O
mwH2O

Uncertainty in $\dot{m}_{vc}$

Measured Variable	Uncertainty
$P_{0,RH}$	0.023%
$T_{0,RH}$	0.23 – 0.3%
RH	1%
D	0.011%
d_c	0.013%
P_0	0.007%
T_0	0.25 – 0.39%
DP	0.0015 in H_2O
C_d	varies



Conclusion

- As compressor cores continue to become smaller, better accuracy of low mass flow measurements is necessary
- Using a set of Critical Flow Venturis, the W7 high speed compressor facility V-Cone was calibrated to under 1% uncertainty for mass flows between 3.6 and 10 kg/s
- Below 3.6 kg/s, the uncertainty is dominated by the differential pressure transducer

Acknowlegement

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