TURBINE MASS FLOW EVALUATION IN A COMPRESSION TUBE FACILITY

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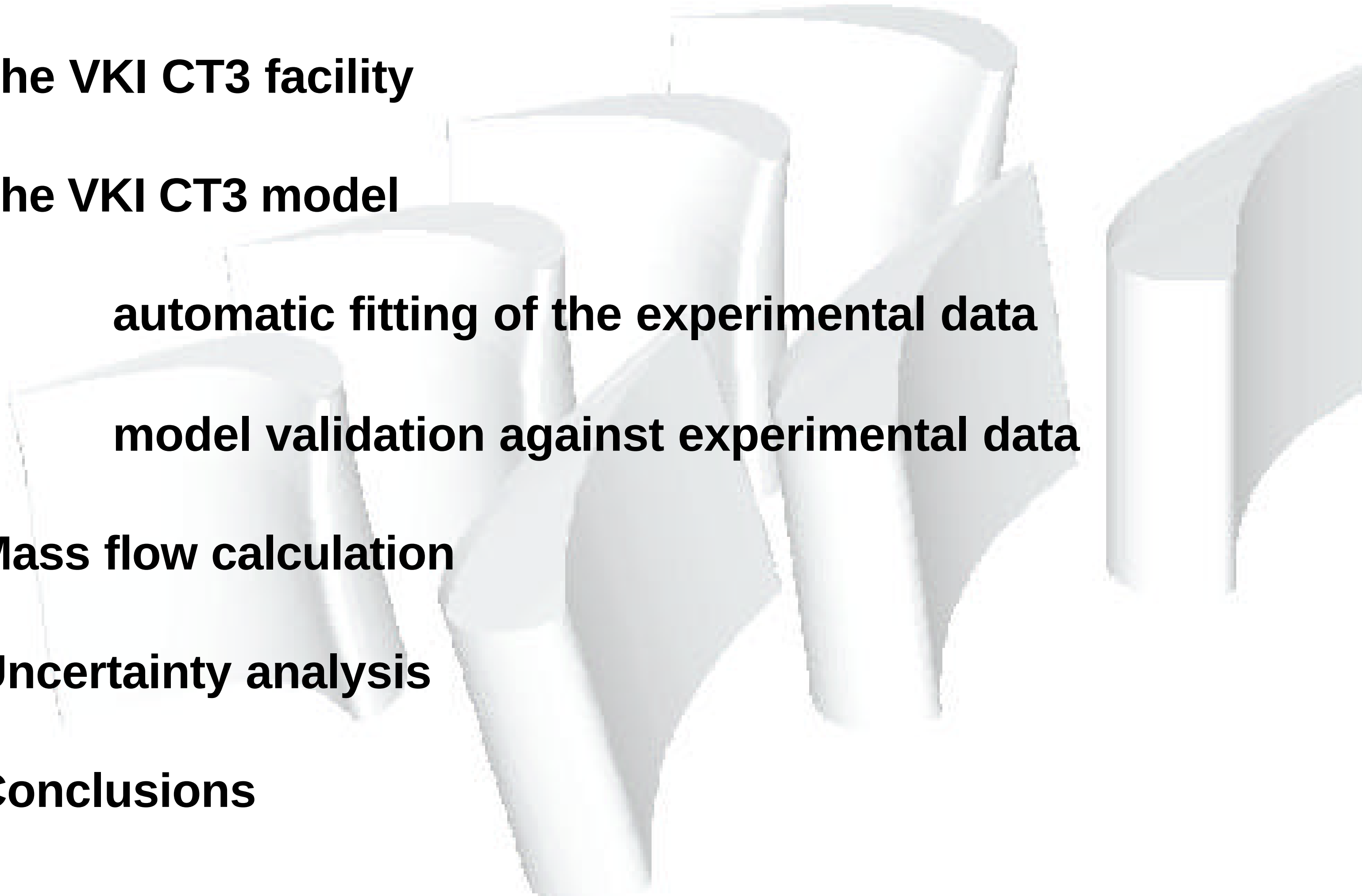

- **The VKI CT3 facility**
- **The VKI CT3 model**
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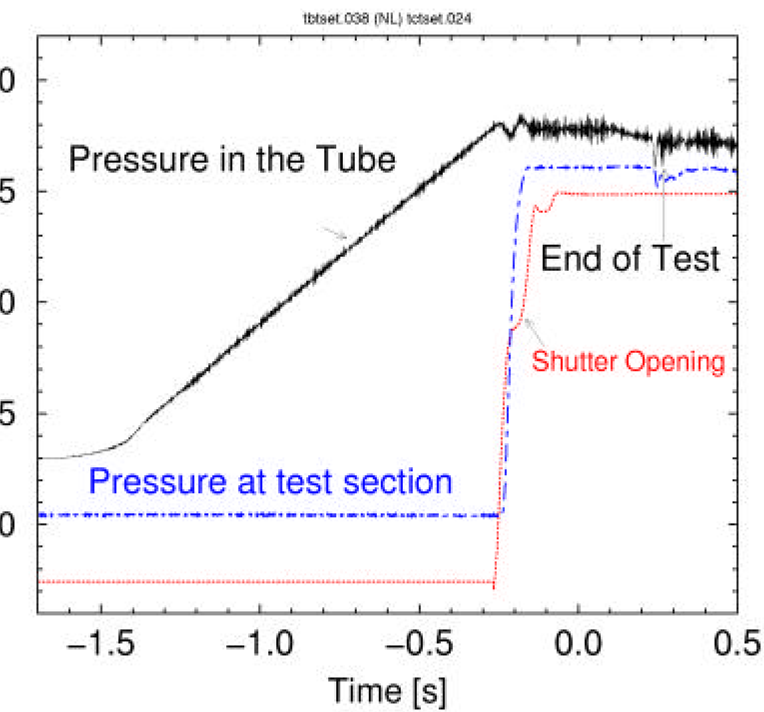
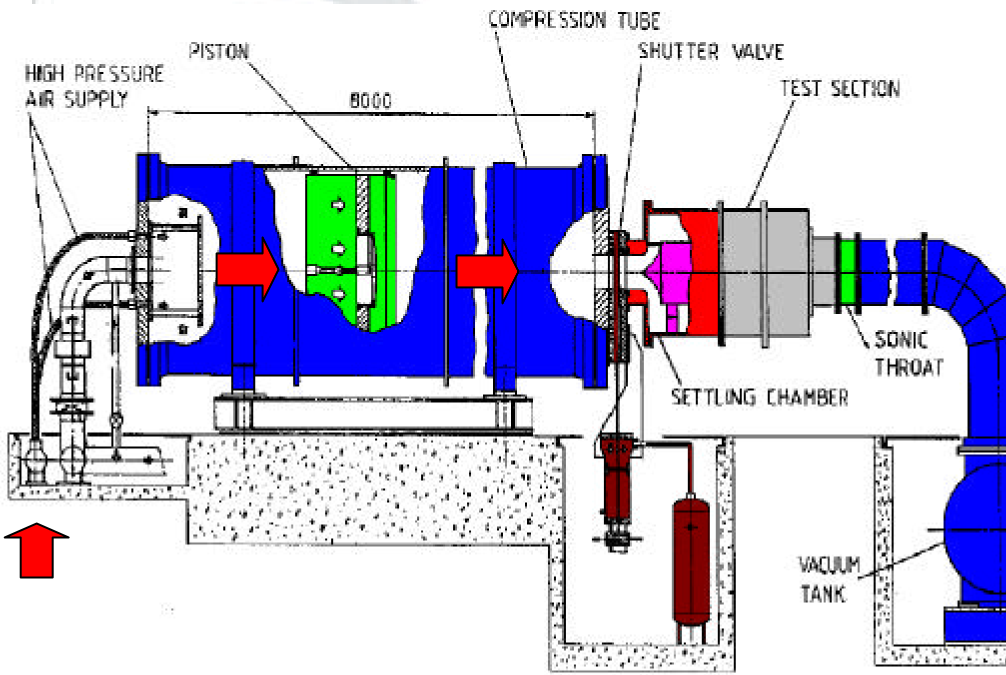
The VKI CT3 Facility





- Fully annular cascade facility
- Variable Reynolds and Mach number
- RPM equal to 6500
- Test time below 0.4 s

Modelisation of the compression tube

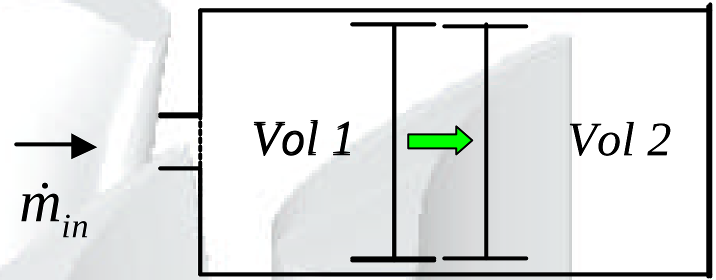
hutter valve closed

$$n_1 = m_1{}^i - m_1{}^{i-1} = \dot{m}_{in}\Delta t$$ mass conservation

$${}^i u_1{}^i - m_1{}^{i-1} u_1{}^{i-1} = \dot{m}_{in} h_{in}\Delta t$$ energy balance

$$V_1{}^i = m_1{}^i R T_1{}^i$$ perfect gas

$$= c_v T^i$$



vo logical step

the piston is blocked in its position

- Volume 1: injection of Δm_{in}

$$T_{01}{}^i = T_{01}{}^{i-1} + \frac{x_1}{1+x_1}\left(gT_{in} - T_{01}{}^{i-1}\right)$$

$$P_{01}{}^i = P_{01}{}^{i-1}\left(1 + \frac{gT_{in}}{T_{01}{}^i} x_1\right)$$

$$x_1 = \frac{\Delta m_{in}}{m_1{}^i}$$

➡ the piston is sliding until p_2=p_1

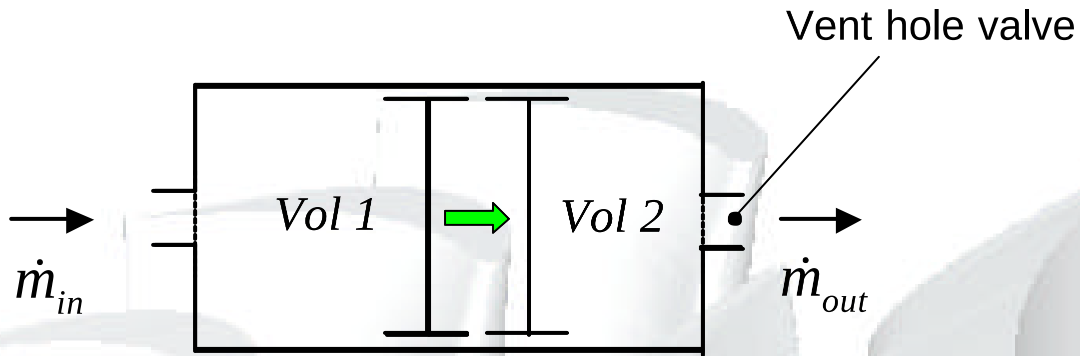
- No mass is admitted

- Volume 1 and 2: isentropic evolu

$$\frac{P_1{}^i}{P_1{}^{i-1}} = \left(\frac{V_1{}^{i-1}}{V_1{}^i}\right)^g$$

$$\frac{T_1{}^i}{T_1{}^{i-1}} = \left(\frac{P_1{}^i}{P_1{}^{i-1}}\right)^{\frac{y-1}{g}}$$

hutter valve opened



the piston is blocked in its position ⇨ the piston is sliding until p_2=$p_$

- Volume 1: injection of Δm_{in}
- Volume 2: ejection of Δm_{out}

$$T_{01,02}{}^{i} = T_{01,02}{}^{i-1} \pm \frac{x_{1,2}}{1+x_{1,2}}\left(gT_{in,out} - T_{01,02}{}^{i-1}\right)$$

$$P_{01,02}{}^{i} = P_{01,02}{}^{i-1}\left(1 \pm \frac{gT_{in,out}}{T_{01,02}{}^{i}} x_{1,2}\right)$$

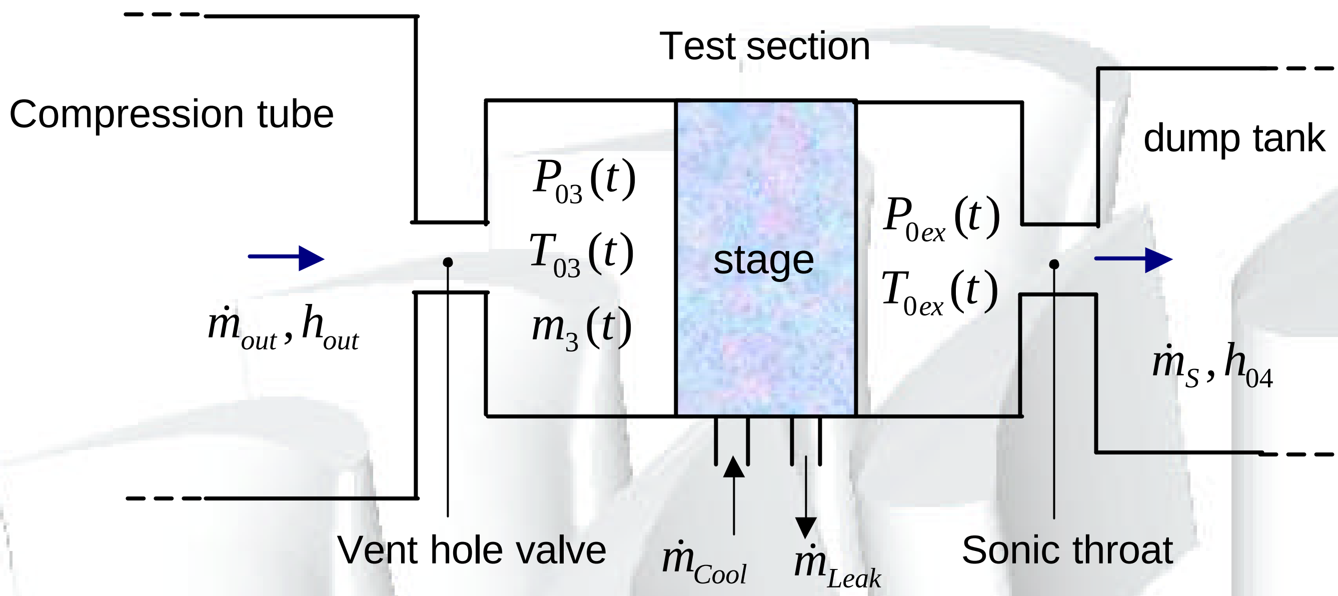
$$x_1 = \frac{\Delta m_{in}}{m_1{}^{i}} \qquad x_2 = \frac{\Delta m_{out}}{m_2{}^{i}}$$

- No mass is admitted or ejected
- Volume 1 and 2: isentropic evolu

$$\frac{P_1{}^{i}}{P_1{}^{i-1}} = \left(\frac{V_1{}^{i-1}}{V_1{}^{i}}\right)^{g}$$

$$\frac{T_1{}^{i}}{T_1{}^{i-1}} = \left(\frac{P_1{}^{i}}{P_1{}^{i-1}}\right)^{\frac{y-1}{g}}$$

Modelisation of the test section



alance of mass flows and internal energy:

$$T_{03}{}^{i} = \frac{g\,(x_{out}T_{0out} + x_{Cool}T_{0Cool} - x_{Leak}T_{0Leak}) + T_{03}{}^{i-1}}{1 + x_{out} + x_{Cool} - x_{Leak} + x_S\,(g-1)}$$

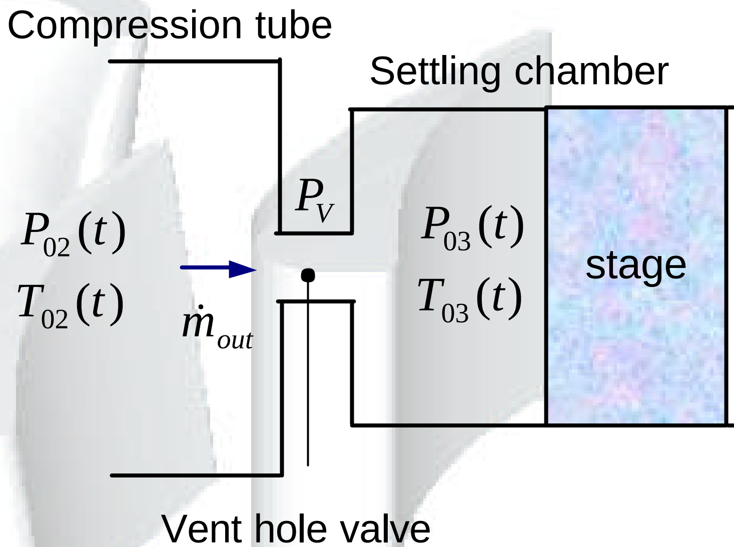
$$P_{03}{}^{i} = \frac{m_3{}^{i}\,RT_{03}{}^{i}}{V_3}$$

Mass flow $\dot{m}_{out}$ evolution

Choked condition

$$\dot{m}_{out} = \frac{P_{02} A_V(t)}{\sqrt{T_{02}}} Const$$

Shutter opening law $A_V(t)$ is implemented



Unchoked condition

Static pressure p_v is artificially coupled to P_{02}

$$P_{02}{}^{i} - P_{V}{}^{i} = \Delta P_c - \Delta P_{TS}{}^{i}$$

$\Delta P_{TS}{}^{i}$ ➡ difference between $P_{02}(t)$ and $P_{03}(t)$

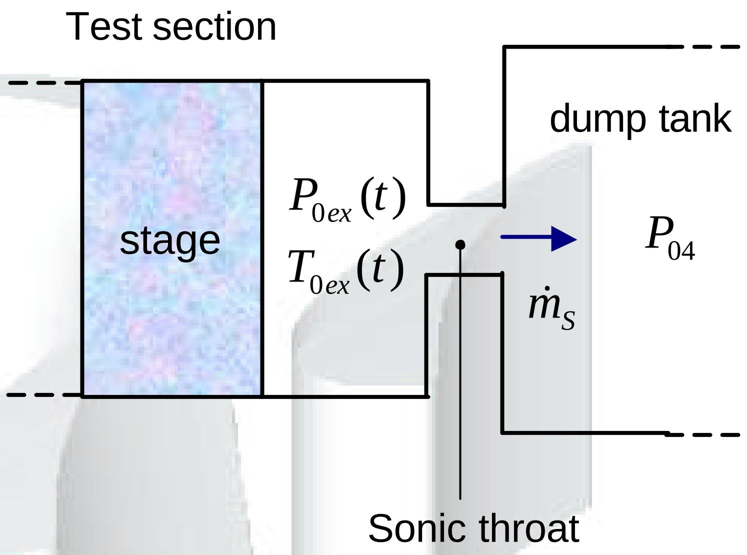
ΔP_c ➡ difference between $P_{02}(t)$ and p_v in steady condition (knowledge of Mach number)

urbine stage

rom the stage pressure ratio:

$$P_{0ex} = \frac{P_{03}}{p}$$

$$T_{0ex} = T_{03}\left[1-h\left(1-p^{\frac{1-g}{g}}\right)\right]$$



lass flow $\dot{m}_S$ evolution

rom the pressure ratio $P_{0ex}(t)/p_4(t)$:

$$\dot{m}_S = \frac{p_4}{RT_4} A_S \sqrt{gRT_4}$$ unchoked condition

➡ $$\dot{m}_S = \frac{P_{0ex}(t)}{\sqrt{T_{0ex}(t)}} A_S \cdot Const$$ choked condition

A_S ➡ sonic throat area

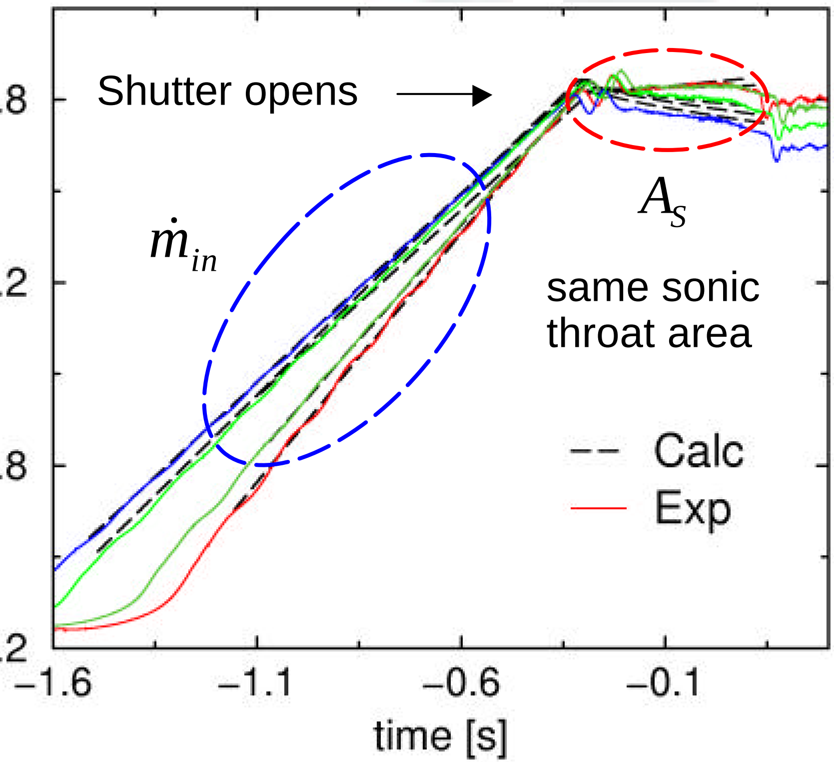
ump tank ➡ closed volume with injection of $\dot{m}_S$

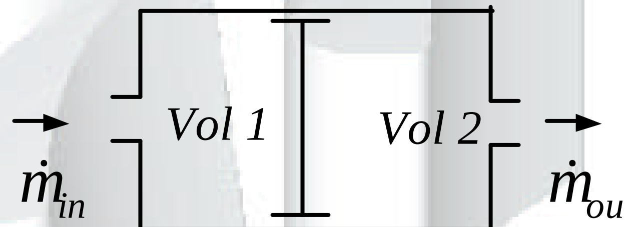
Validation against the experimental data

tial conditions: initial tube pressure and temperature

o parameters are needed: $\dot{m}_{in}$ and A_S

Fitting of the tube pressure evolution





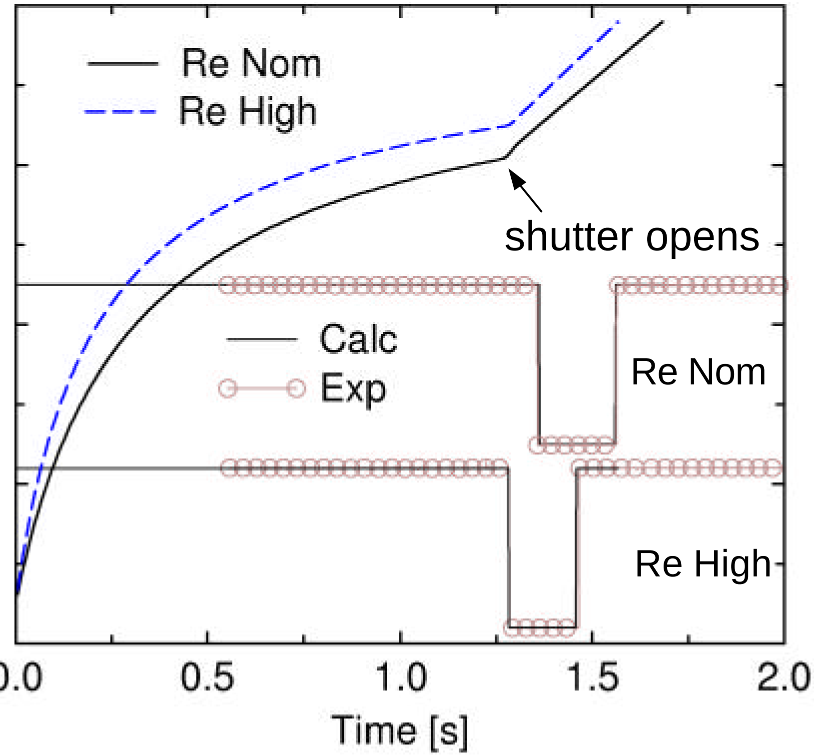
"Matching conditions" ➡ $\frac{\dot{m}_{in}}{r_{in}} = \frac{\dot{m}_{ou}}{r_{ou}}$

significant test to test variation of the pressure slope ➡ non perfect match

The model is able to calculate the mass flow for each test

Validation against the experimental data

ston displacement



- piston is decelerating until the shutter opens

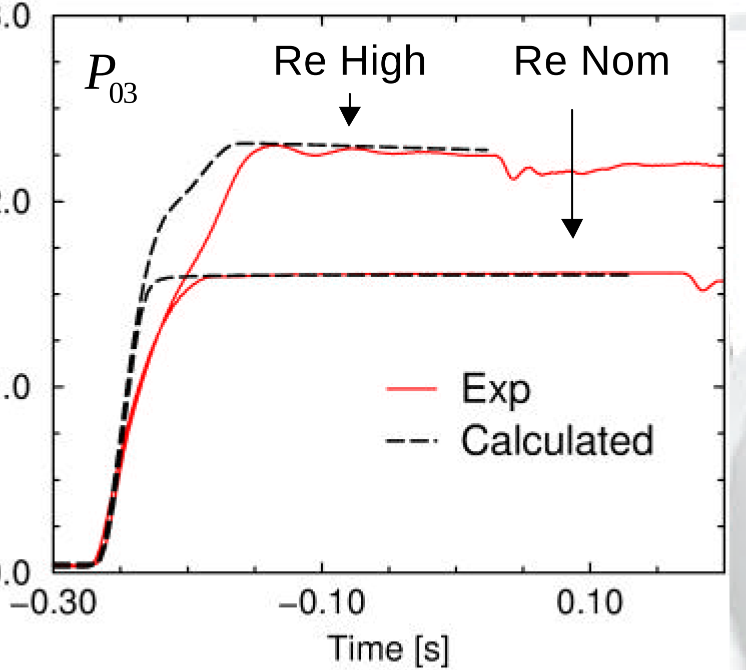
- piston velocity is constant during the blowdown

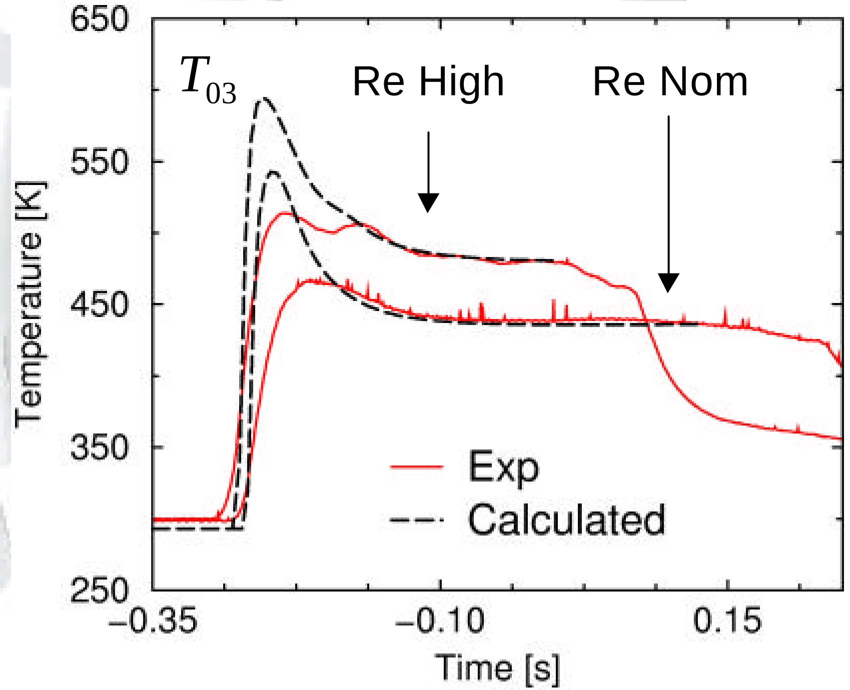
- good agreement between calculated ar measured detection signals

isentropic assumption is reasonal

Validation against the experimental data

ressure and temperature in the test section





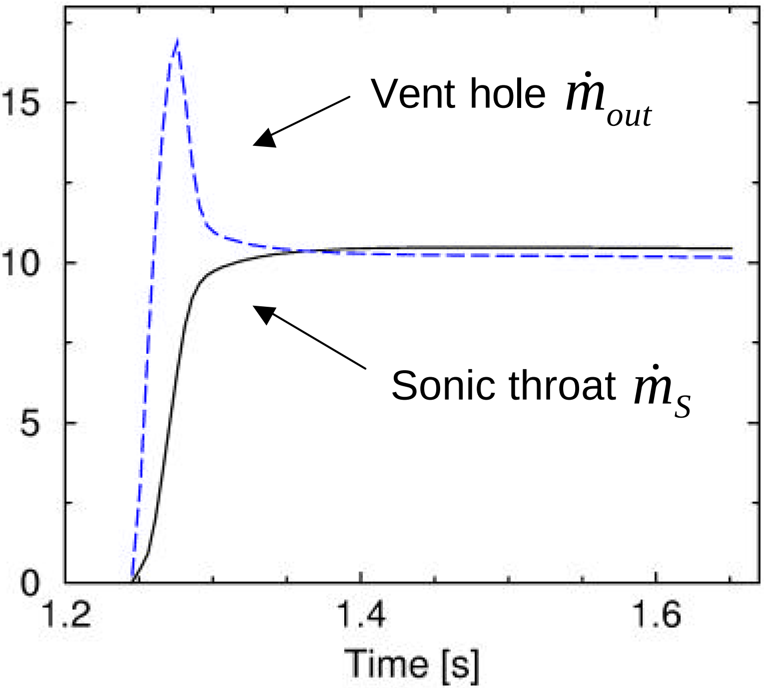
he steady value of P_{03} and T_{03} is set by imposing the losses

he transient and test time is well predicted

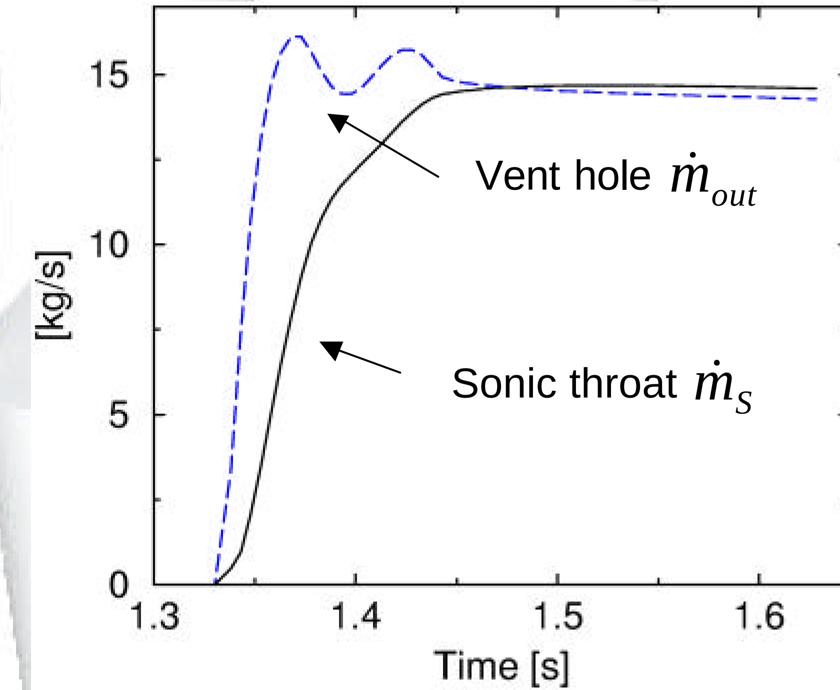
he peak in the temperature is due to the sudden compression in the settling hamber

Mass flow evaluation: results

Re Nom



Re High



he mass flows are matching after the transient time

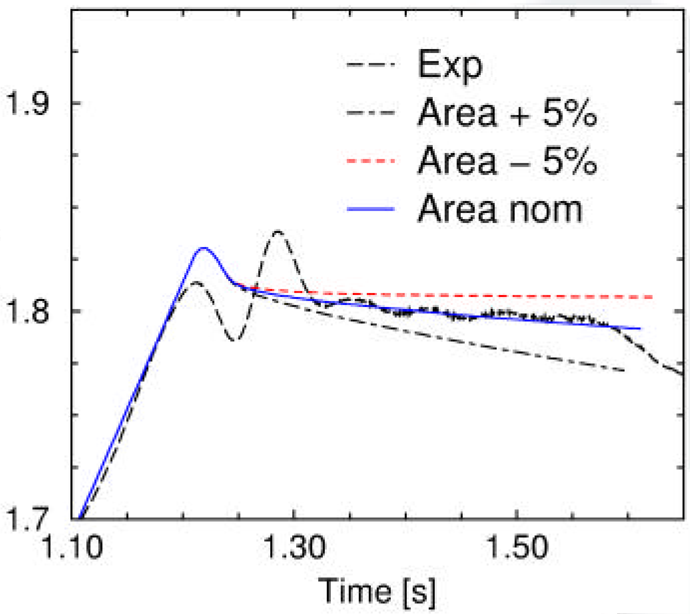
he difference between $\dot{m}_{out}$ and $\dot{m}_{S}$ is provided by the coolants and the akage flows

Mass flow evaluation: uncertainty analysis

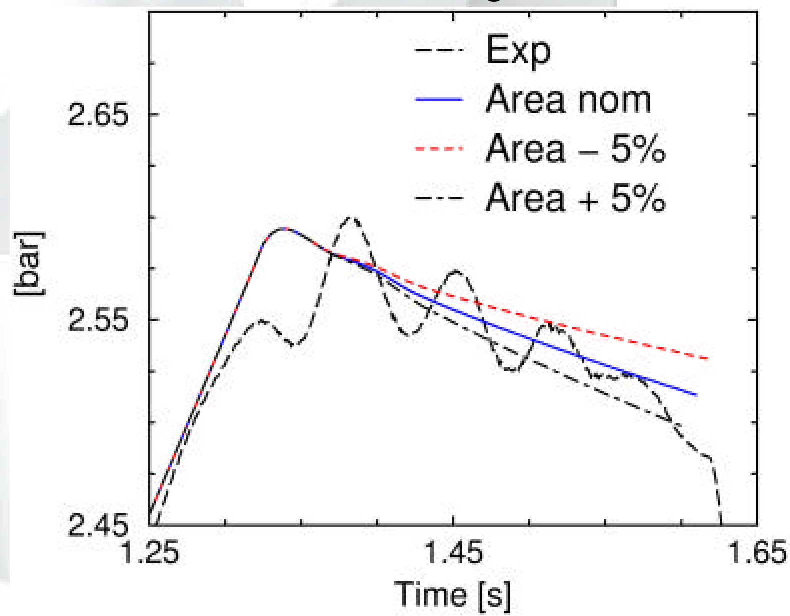
most critical parameter: sonic throat area

% of area variation ⟹ 0.62% in the mass flow

Re Nom



Re High



Jncertainty in the slope detection provides an inaccuracy in the sonic throat ar
mputation

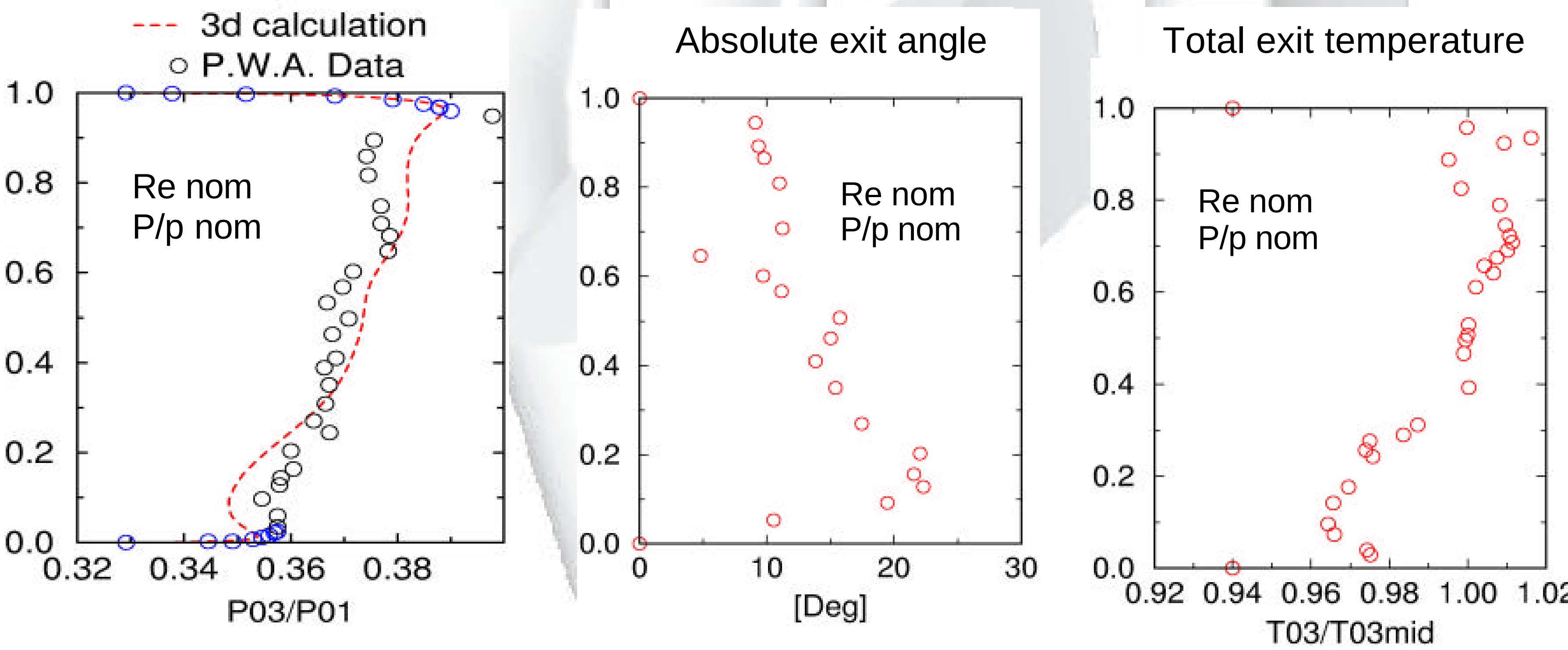
he uncertainty is larger at High Reynolds than at Nom Reynolds

Mass flow evaluation: using P.W.A. Data

ass flow calculation from the integration of the

tchwise averaged data $P_{0ex}, T_{0ex}, a_{ex},$

Most sensitive parameter ⇨ Downstream Total pressure



Mass flow evaluation: results

1 stage	Ct3 Model	P.A.Profile
P/p Nom Re Nom [kg/s]	10.55	10.54
P/p Nom Re Low [kg/s]	10.1	10.52
Uncertainty	+/- 0.82 %	+/- 3.92 %
Dispersion	+/- 1.43 %	
1 and ½ stage		
without rotor cooling [kg/s]	15.27	-
2% rotor cooling [kg/s]	15.35	-
3% rotor cooling [kg/s]	15.36	-
Uncertainty	+/- 1.6 %	
Dispersion	+/- 0.21 %	

Conclusions

- A model of the VKI CT3 facility is developed and validated
  - simple approach
  - the isentropic compression assumptions is reasonable
  - good agreement between calculated and measured values

- Better understanding of the flow parameters in the test rig
- Stage mass flow calculation is performed

  accurate evaluation for each test (uncertainty of +/- 0.82% or +/- 1.6

  compared with P.W.A. profile calculation

- Easily usable for compression tube facilities

- Usable to predict and/or design different test conditions