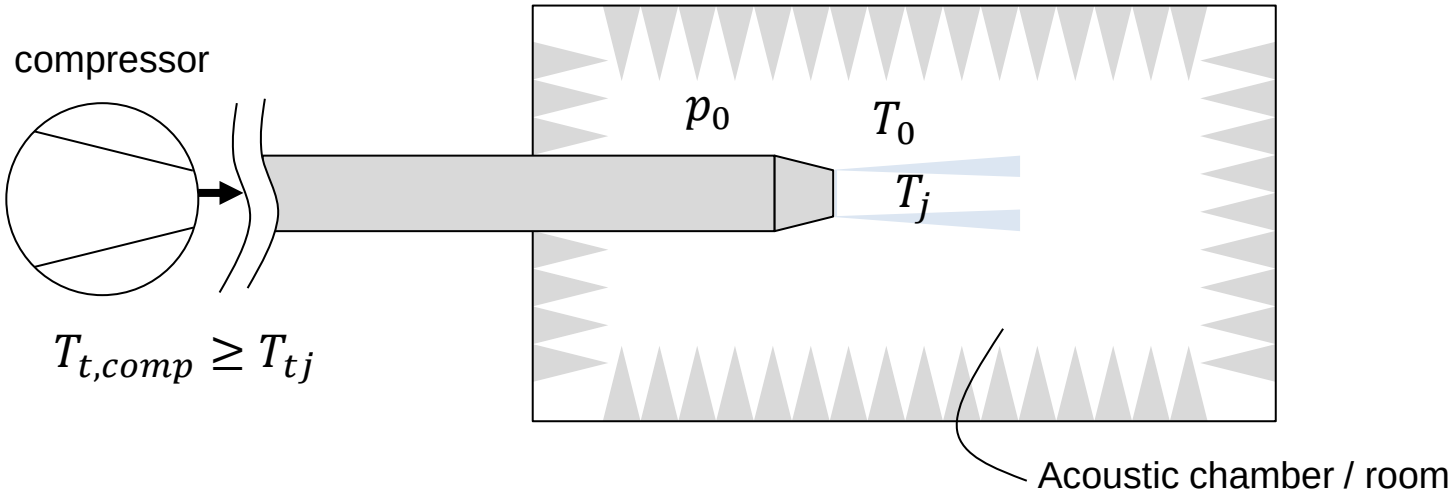
Acoustic Mach number, jet Mach number or jet speed – what is the optimal control property for jet noise experiments at AWB

Christian Jente

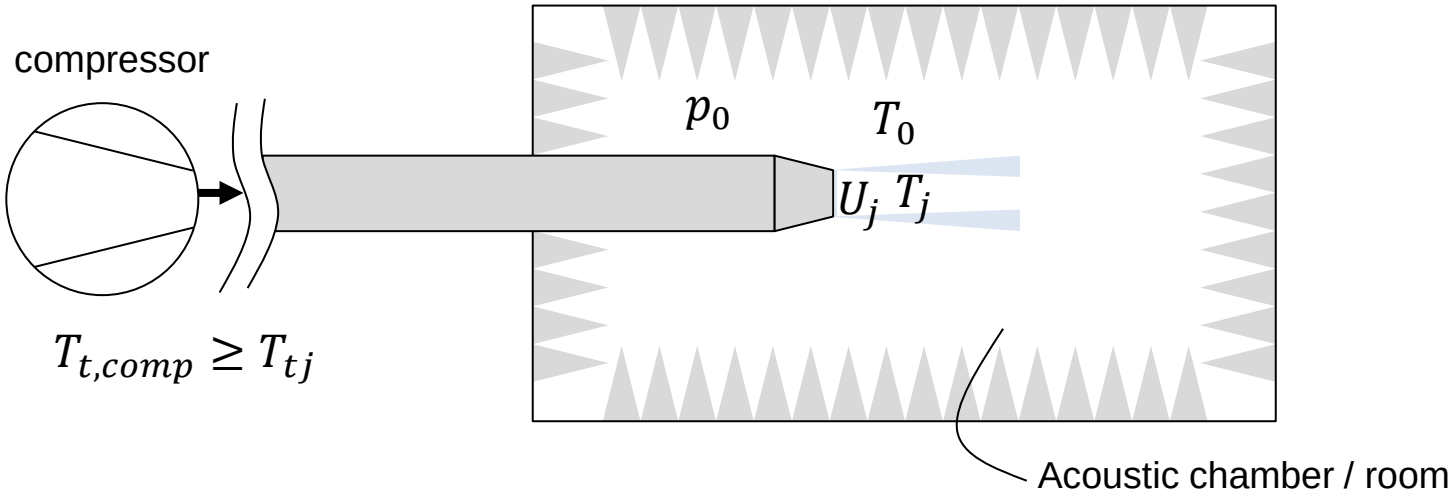
Jet experiment, ISA norm conditions and implications on temperature control



ISA norm test conditions are defined as:

- Acoustic chamber/room pressure $p_0 := 101325\ Pa$
- Acoustic chamber/room temperature $T_0 := 288.15K\ (15°C)$
- Isothermal velocity profile $T_j = T_0$

Definition of Operational conditions



Operational conditions can be defined by

- Jet velocity U_j
- Jet Mach number $M_j := U_j/\sqrt{\gamma R T_j}$
- Acoustic Mach number $M_{ac} := U_j/\sqrt{\gamma R T_0}$

Heat requirements for testing ISA-cold air flow

The measurement of a certain jet velocity requires a moderately heated pressurized air supply - even for cold testing at $15°C$:

- Definition for jet velocity

$$T_{tj} = \overbrace{T_j}^{15°C} + U_j^2/(2c_p)$$

- Definition for jet Mach number

$$T_{tj} = T_j\left(1 + \underbrace{\frac{\gamma-1}{2}}_{=0.2\ (\text{cold air})} M_j^2\right)$$

			for Ø100mm nozzle:	
Jet Mach number Mj [-]	Jet temperature Ttj [K]	Ttj,ISA [°C]	mass flow rate ṁ [kg/s]	heat flow rate* Q̇ [kW]
0	288	15	0.0	0
0.5	303	29	1.64	24
0.6	309	36	1.96	41
0.7	316	43	2.29	65
0.8	325	52	2.62	97
0.9	335	62	2.95	138
1	346	73	3.27	189

*compared to cold/unheated supply piping at T_t=15°C

Ffowcs-Williams‘ modification of Lighthill‘s theory

10th AIAA/CEAS Aeroacoustics Conference

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Noise Scaling for Unheated Low Aspect Ratio Rectangular Jets

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[p.5] The classical result for estimating the acoustic intensity of noise from a jet issuing into a quiescent medium from Lighthill’s theory, modified by Ffowcs-Williams[24] is;

Same jet nozzle

$$I \propto \frac{\rho_m^2 U_j^8 D_j^2}{\rho_o a_o^5 R^2} \frac{1}{\left|1 - M_c \cos(\theta)\right|^5} \qquad (6)$$

Same microphone position

relevant for temperature behaviour of ops

[24] Ffowcs-Williams, J. E. *The Noise from Turbulence Convected at High Speed* Phil. Trans. Royal Society, 1963.

Temperature effects according to Ffowcs-Williams

Ffowcs-Williams: $$I \sim \frac{\rho_m^2 U_j^8}{\rho_0 a_0^5} \quad (5)$$

& mixed density (rough assumption): $$\rho_m \sim \sqrt{\rho_j \rho_0} \quad (6)$$

& ideal gas law jet, subsonic outlet $$\rho_j = \frac{p_0}{R T_j} \quad (7)$$

FW rewritten: $$I \sim \gamma p_0 \frac{U_j^2}{\gamma R T_j} \cdot U_j \cdot \frac{U_j^5}{a_0^5} \quad (8)$$

FW with Mach # def.: $$I \sim \gamma p_0 \cdot M_j^2 \cdot U_j \cdot M_{ac}^5 \quad (9)$$

FW $\gamma p_0 = const.$: $$I \sim M_j^2 \cdot U_j \cdot M_{ac}^5 \quad (10)$$

Please, feel invited to comment on this and/or provide your favorite correction for testing jet noise at non-isothermal static temperatures christian.jente@dlr.de

Correction terms for testing with acoustic Mach number, jet Mach number or jet speed

$$I \sim \frac{U_j^2}{T_j} \cdot U_j \cdot \frac{U_j^5}{T_0^{5/2}}$$

Jet Speed testing $$I \sim U_j^8 \cdot \frac{1}{T_j} \cdot \frac{1}{T_0^{5/2}} \quad (12)$$

Acoustic Mach number testing $$I \sim M_{ac}^8 \cdot \frac{T_0^{3/2}}{T_j} \quad (11)$$

Jet Mach number testing $$I \sim M_j^8 \cdot \frac{T_j^3}{1} \cdot \frac{1}{T_0^{5/2}} \quad (13)$$

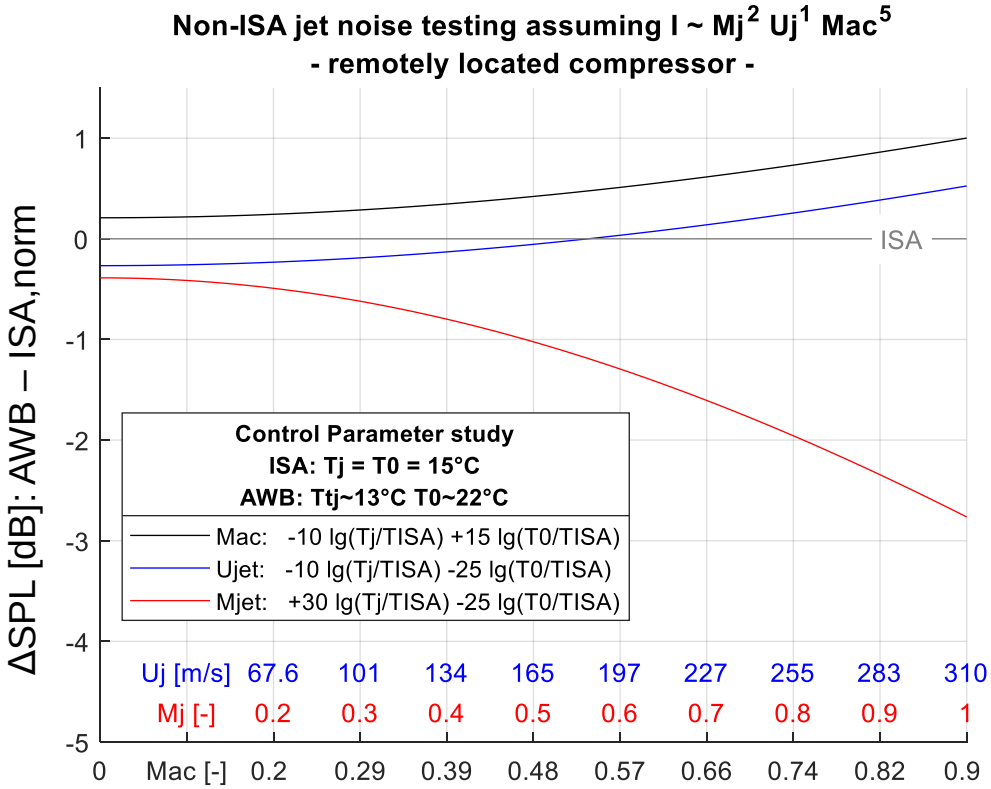
Isothermal measurement?

→ Jet noise scales with power 8 of jet velocity as well as acoustic and jet Mach number

AWB-conditions?

→ Jet too cold T_{tj}=13°C / ac. room too warm T_0=23°C (compared to 15°C ISA)

Correction curves for operations at AWB



- Sensitivity:
  U_{jet} & M_{ac} opposite to M_j

- For smallest delta to ISA-conditions:

  Choose jet speed U_j as control parameter at AWB

Questions / Comments?

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