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

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## Abstract

**Some experimental facilities are planned energy-lean, but this comes typically with slightly imperfect test conditions. Especially temperature control systems are often slow, demand energy and increase operational cost. Contrary to this, low-cost experimental pressurized air test rigs, such as the one at AWB (Acoustic Wind tunnel Braunschweig), respond to control commands much faster, but do not meet norm conditions.**

**Therefore, the question needs to be answered which flow parameter should be used for operation control, the acoustic Mach number $M_{ac}$, jet Mach number $M_j$ or jet velocity $U_j$.**

**This study starts with the definition of ideal ISA norm conditions and a re-writing of the Ffowcs-Williams jet noise analogy without any temperature terms. Using a rough assumption for the mixed (shear layer) density, the jet noise scales according to $I \sim M_j^2\, U_j\, M_{ac}^5$.**

**The derivation will be used in order to judge the three control options at a test rig with a constant total temperature for the jet.**

**As a result, this study will recommend the testing of jet velocities for jet noise experiments at AWB.**

## Jet experiment, ISA norm conditions and implications on temperature control

The jet noise measurement test rig consists of a pressurized air supply system which delivers jet flow at a certain (here: constant) total temperature $T_{tj}$. The jet propagates into an acoustic chamber or room which is characterized by its pressure $p_0$ and temperature $T_0$.

ISA norm test conditions are defined as:

Acoustic chamber pressure $\quad p_0 := 101325\, Pa \quad$ (1)

Acoustic chamber temperature $\quad T_0 := 288.15K\ (15°C) \quad$ (2)

Isothermal velocity profile $\quad T_j = T_0 \quad$ (3)

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 $\quad T_{tj} = T_j + U_j^2/(2c_p) \quad$ (4)

## Temperature effects according to Ffowcs-Williams

Ffowcs-Williams' modification [1] of Lighthill's theory is commonly used for estimating the acoustic intensity of static jet noise, e.g. [2]. This study focuses on the density/velocity terms only. This means that jet area as well as mic distance & directivity are assumed to be constant. The fluid density $\rho_m$ is assumed to be a mixed density between jet and acoustic chamber, and dimensionally approximated by the geometric mean (not: arithmetic mean).

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

& Mixed density *dimensional assumption*: $\quad \rho_m \sim \sqrt{\rho_j \rho_0} \quad$ (6)

& Ideal gas law jet, subsonic outlet $\quad \rho_j = \frac{p_0}{RT_j} \quad$ (7)

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

According to the derived analogy jet noise is proportional to jet Mach number squared times jet velocity and acoustic Mach number $I \sim M_j^2\ U_j\ M_{ac}^5$. Hot temperature "same-jet Mach number" jets scale with $I \sim U_j\ M_{ac}^5 \sim U^6$. Very fast (& perfectly expanded) supersonic "same-jet speed" jets scale with $I \sim M_j^2$.

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

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

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

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

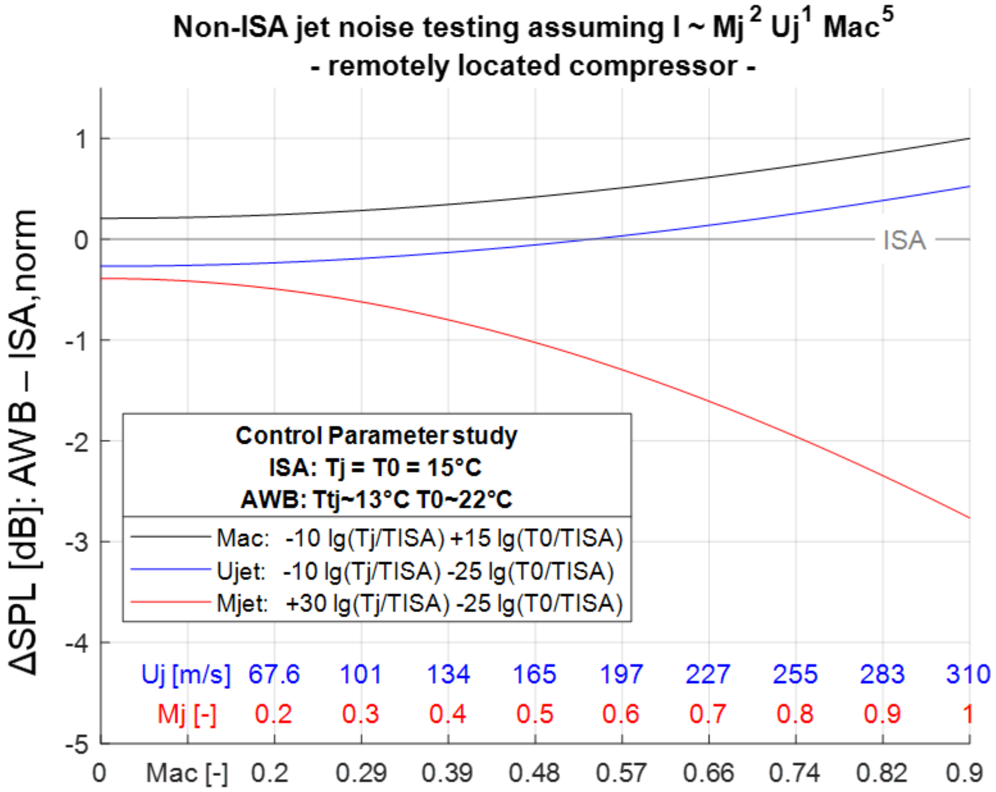


**Fig. 1** Correction curves for each control parameter

The calculated correction curves for the model indicate that the lowest correction is expected when choosing jet speed $U_j$ as control parameter at AWB. Experiments controlled with Jet Mach number may produce spectra which need a rather large correction of almost 3dB at $M_j$=1. Sonic test conditions ($M_j$=1) are reached at AWB for $U_j$~310 m/s and $M_{ac}$~0.9.

## References


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

[2] Massey, K.C., Ahuja, K.K., and Gaeta, R., "Noise Scaling for Unheated Low Aspect Ratio Rectangular Jets," AIAA Paper 2004-2946, May 2004.