Specifications for the generic academic configuration for the validation of numerical (HiFi-)CFD codes

F. Gand, ONERA
(adapted for external use by W. Haase, CFD-Berlin)

1. Context and objectives

The objective is to provide specifications for the numerical treatment of two test jet cases, being run within the DJINN project for code validation – amongst other cases. These two test cases (as simplified configurations) are now released to any other colleague interested in noise studies and optimization of jet-airframe interaction noise. The main goal is to apply advanced methods to a demonstrate jet noise prediction accuracy up to St=10.

This report presents the experimental databases which have been selected by the DJINN consortium to be used as reference for the validation. Recommendations are given for the setup of the simulations and the assessment of the results to ensure that all simulations are carried out with the same flow conditions for enabling cross comparison of results.

It should be noted that in case of further questions and/or requests, the coordinator of the DJINN project, W. Haase (CFD-Berlin) should be contacted. Questions and queries will then be conveyed to the colleagues from CNRS and Southampton University (SOTON).

2. Generic test case - CNRS

2.1 Isolated nozzle

The reference publication for the Generic Test Case – CNRS experiments is given by [1]. The experiments were carried out at the Pprime laboratory (based in Poitiers, France). The exhaust Mach number is equal to M=0.9, the nozzle exit diameter is D=0.05 m, the total pressure ratio is P_i/P_∞=1.7, and the total temperature ratio is T_i/T_∞=1.15. The Reynolds number based on the diameter is equal to $Re_D=10^6$. All experimental data, as well as the nozzle geometry are online available [2]. The geometry of the convergent-straight nozzle is shown in Fig. 1.

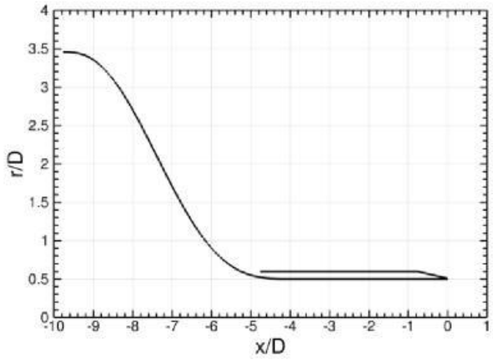

Fig. 1 CNRS nozzle geometry; data available online [2]

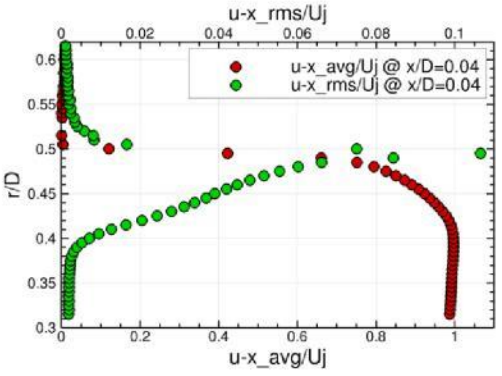

Fig. 2 Nozzle exit boundary layer for CNRS isolated case; data from [2]

The nozzle exit boundary layer was tripped to reach a turbulent state at the nozzle exit. The mean and RMS streamwise velocity profiles at the nozzle exit (x/D=0.04) are shown in Fig. 2. Flow measurements (hot wire) are available for radial profiles at x/D=0.04, 1, 5, 10, 15 and axial profiles at r/D=0 (jet centerline) and 0.5 (lip-line). Noise measurements were performed using arrays of microphones at locations given in Table 1, below.

(a)	x/D	r/D	ϕ (deg.)	(b)	x/D	r/D	ϕ (deg.)	(c)	x/D	r/D	ϕ (deg.)
	0.12	0.72	99.5		0	14.3	90		0	50.00	90
	2.00	0.98	153.9		3.83	14.3	105		8.68	49.24	100
	2.62	1.07	157.8		8.25	14.3	120		17.10	46.98	110
	3.42	1.18	160.1		14.30	14.3	135		25.00	43.30	120
	4.47	1.33	163.4		17.04	14.3	140		32.14	38.30	130
	5.85	1.52	165.4		20.42	14.3	145		38.30	32.14	140
	7.65	1.78	166.9		24.77	14.3	150		43.30	25.00	150
					30.66	14.3	155		46.98	17.10	160
					39.29	14.3	160				

Table 1 Coordinates x–r and corresponding jet inlet angle Φ of the microphones for (a) the near-field cage array, (b) the cylindrical array and (c) the polar array. From [1]

Noise measurements in the jet mid-field (cylindrical array at r/D=14.3) and farfield (polar array are r/D=50) are shown in Fig. 3. This illustrate the noise levels at St=10, which are low but measurable, therefore this case appears relevant to assess "St=10" CFD simulations. The experimental data is presently only available only up to St=8, but a revised dataset with measurements up to St=10 will be made available by CNRS.

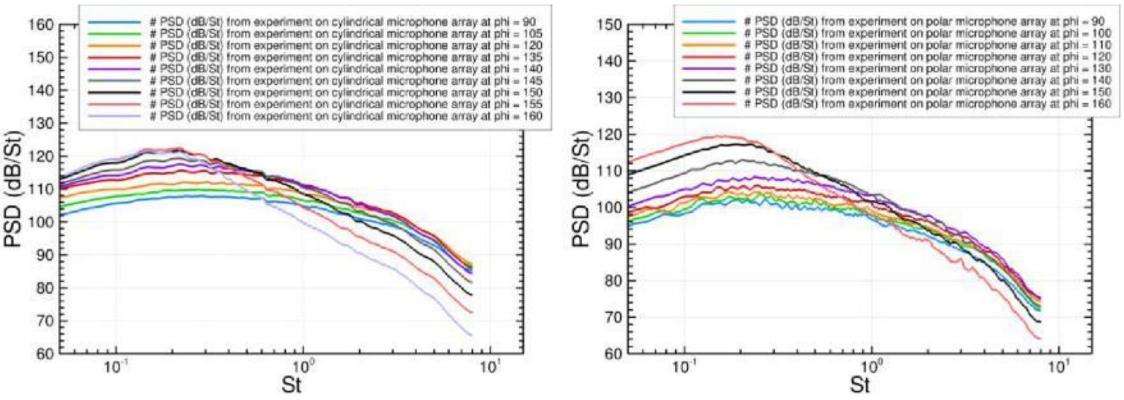

Fig. 3 PSD of pressure for the cylindrical array (left) and polar array (right). CNRS-Isolated case,;data from [2]

2.2 Installed nozzle

The reference publication for the CNRS-installed case is [3]. The geometry is illustrated in Fig. 4. The wing is modelled by a flat plate which trailing edge sweep can be varied. In the framework of the GTC specification for the DJINN project, the zero-sweep trailing edge flat plate is selected. The flat plate is located at H/D=0.6 and L/D=4 (H is the normal distance from the nozzle lip to the plate surface, L is the streamwise distance between the nozzle exit and the plate trailing edge).

The flow conditions and measurement locations are the same as the isolated case presented in section 2.1 and are summarized at the end of this report in Table 2.

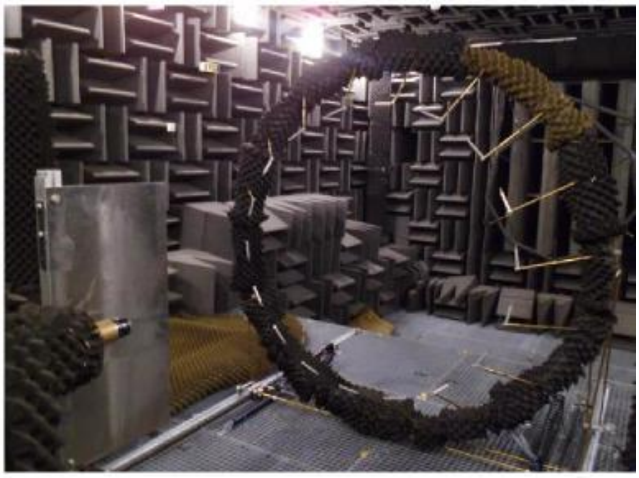

Fig. 4 CNRS-installed case. From [3]

3. Generic test case - SOTON

3.1 Isolated nozzle

The isolated case from SOTON is a jet issuing from a conical nozzle of diameter D = 40 mm at M = 0.8 as illustrated in Fig. 5. Information regarding the experimental facility and nozzle geometry can be found in [4], however only M=0.6 data are investigated in this article. Data for the M=0.8 case will be provided by SOTON on request. The nozzle exit boundary layer profile is illustrated in Fig. 6.

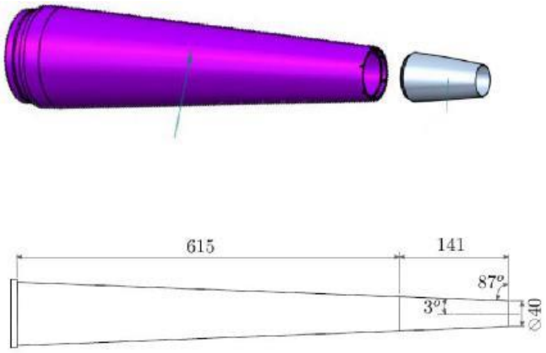

Fig. 5 SOTON-isolated case. From [4]

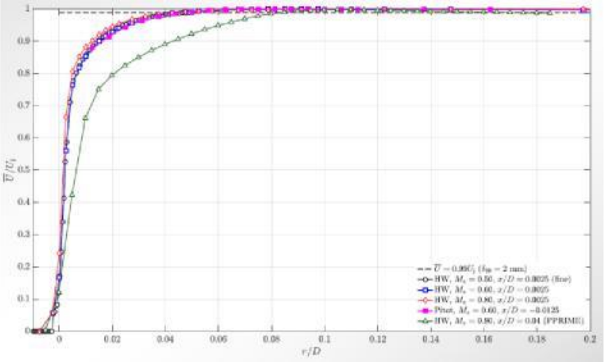

Fig. 6 Nozzle exit boundary layer profile

Flow measurements were carried out using a hot wire probe, all across the jet plume. Noise measurements were performed in the jet near field for radial locations r/D in [1;2] and at streamwise locations x/D=1, 2, 3. The farfield noise was measured at r/D = 54 D and 80 D.

The SPL levels for the M=0.8 considered as GTC-SOTON-isolated are depicted in Fig. 6 to confirm that there is measurable noise at St=10 and that this case is relevant to assess the HiFi-CFD simulations.

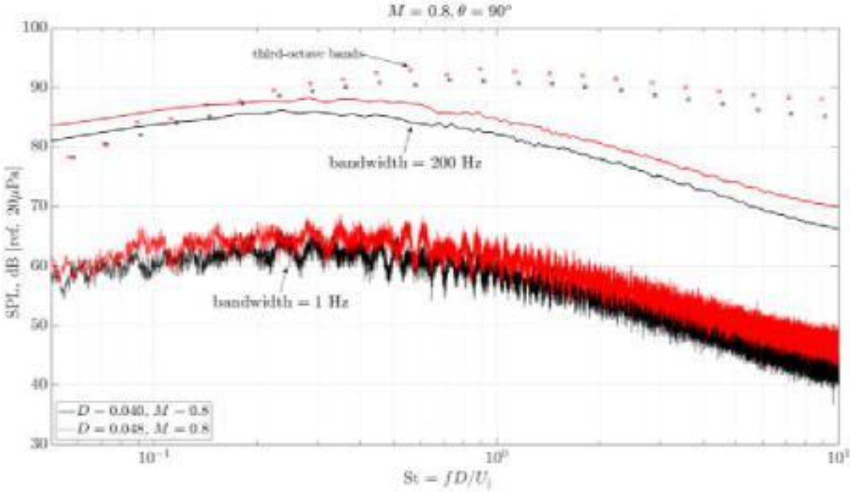

Fig. 7 Sound Pressure Levels (right) for SOTON-isolated case

3.2 Installed nozzle

The installed case selected as GTC-SOTON-installed involves the same conical nozzle as the isolated case and a NACA4415 wing located at H/D=0.6 and L/D=3 (H is the normal distance from the nozzle lip to the wing surface, L is the streamwise distance between the nozzle exit and the wing trailing edge). The nozzle exit Mach number is M=0.6 and a flight stream at M=0.1 is included. Data for this case have not been published yet but will be distributed by SOTON on request.

The measurement locations are the same as the isolated case presented in section 2.1 and are summarized at the end of this report in Table 2.

4. Procedure suggested for simulations setup

To perform consistent and relevant comparisons with experiments and between simulations, it is expected that the simulations match the flow conditions of the experiments in terms of Reynolds number, total pressure, and temperature ratios. Besides, the exit boundary layer profiles will have to be matched as best as can be, for the mean and RMS values.

5. Preliminary recommendations for results assessment

To facilitate cross comparisons, it is expected that each contributor

- extracts simulation data (at least) at the experimental locations documented in the previous sections
- is taking much care in the post-processing of the noise data, which must follow the procedure used for the corresponding experiment. Such procedure is detailed in [1] for the CNRS-isolated case, SOTON will provide the needed information

6. Summary of the generic test case flow conditions

Two variants of the Generic Test Case (GTC) have been defined: GTC-CNRS and GTC-SOTON. Each GTC variant is composed of an isolated nozzle case and an installed case. It is suggested that the isolated case must be computed first, the installed case can be simulated in a second step to mitigate risks regarding the handling of geometric complexity by HiFi-CFD methods. Table 2 summarizes the flow conditions of the experiments of GTC-CNRS and GTC-SOTON.

	GTC-CNRS		**GTC-SOTON**	
Facility	Bruit & Vent		Doak Laboratory	
Case	**Isolated**	**Installed**	**Isolated**	**Installed**
Geometry				
Nozzle type	Round single stream, convergent-straight		Round single stream, conical (half-angle=2.3°)	
Nozzle exit diameter D (m)	0.05		0.04	
Wing/plate geometry	n/a	Rectangular flat plate H/D=0.6, L/D=4	n/a	NACA4415 H/D=0.6; L/D=3
Flow conditions				
Nozzle exit acoustic Mach number Mj	0.9	0.9	0.8	0.6
Jet temperature Tj (K)	Tj/Ts=1	Tj/Ts=1	Tj/Ts=1	Tj/Ts=1
Jet Reynolds number based on diameter ReD	10^6	10^6	$7.35\ 10^5$	$5.52\ 10^5$
Nozzle exit boundary layer thickness δ_{99} (m)	0.004	Not measured but O(0.004)	0.00168	Not measured but O(0.00188)
Nozzle exit boundary layer momentum thickness θ (m)	0.0004	Not measured but O(0.0004)	0.00013	Not measured but O(0.00014)
Flight stream	No	No	No	M=0.1
Measurement locations				
Flow in the jet plume	PIV in (x-r) planes	No flow measurements at M=0.9	2-point 2-cmpt hot-wire, 0≤x/D≤15	1-point 1-cmpt hot-wire, 0≤x/D≤10
Nozzle exit boundary layer profiles	available	not measured (by default, use isolated profile at same Mach as target)	available	not measured (by default, use isolated profile at same Mach as target)
Nacelle external boundary layer (if flight stream)	n/a	n/a	n/a	not measured
Noise: near field pressure	0.12<x/D<7.65; 0.7<r/D<1.8 (cage array)	No	Δϕ=45°, 1≤r/D≤2, x/D=1, 2, 3	not measured
Noise: far-field pressure	r=14.3D & r=50D	r=14.3D & r=50D	40°≤θ≤150°, r_{90}/D=70	40°≤θ≤150°, r_{90}=54D; r_{40}=80D

Table 2 Summary of the Generic Test Cases selected

7. References

[1] G. A. Brès, P. Jordan, V. Jaunet, M. Le Rallic, A. V. G. Cavalieri, A. Towne, S. K. Lele, T. Colonius and O. T. Schmidt, "Importance of the nozzle-exit boundary-layer state in subsonic turbulent jets," *Journal of Fluid Mechanics,* vol. 851, pp. 83-124, 2018. doi: 10.1017/jfm.2018.476.

[2] G. A. Brès, P. Jordan, V. Jaunet, M. Le Rallic, A. V. G. Cavalieri, A. Towne, S. Lele, T. Colonius and O. T. Schmidt, "Data from "Importance of the nozzle-exit boundary-layer state in subsonic turbulent jets"," [Online]. Available: https://static.cambridge.org/content/id/urn:cambridge.org:id:article:S0022112018004767/resource/name/S0022112018004767sup001.zip.

[3] S. Piantanida, V. Jaunet, J. Huber, W. R. Wolf, P. Jordan and A. V. G. Cavalieri, "Scattering of turbulent-jet wavepackets by a swept trailing edge," *The Journal of the Acoustical Society of America,* vol. 140, pp. 4350-4359, 8 2016. doi: 10.1121/1.4971425.

[4] A. R. Proença, J. L. Lawrence and R. H. Self, "Experimental Investigation into the Turbulence Flowfield of In-Flight Round Jets," *AIAA Journal,* vol. 58 (8), pp. 3339-3350, 2020. doi: doi.org/10.2514/1.J059035.