SAE The Engineering Society For Advancing Mobility Land Sea Air and Space®
INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

SURFACE VEHICLE INFORMATION REPORT

An American National Standard

SAE J2071

REV. JUN94

Issued 1990-03
Revised 1994-06

Superseding J2071 MAR90

AERODYNAMIC TESTING OF ROAD VEHICLES - OPEN THROAT WIND TUNNEL ADJUSTMENT

Foreword—This document has also changed to comply with the new SAE Technical Standards Board format. The document title has also changed.

1. ***Scope***—As a simulation of road driving, wind tunnel testing of full-size vehicles produces certain errors in the aerodynamic forces, aerodynamic moments, and surface pressures. The magnitude of these errors, in general, depends on the following:

   a. Flow quality
   b. Determination of the reference dynamic pressure
   c. Wind tunnel floor boundary layer
   d. Test section geometry and position of the car within that geometry
   e. Shape of the vehicle
   f. Blockage ratio: The ratio of the cross-sectional area of the vehicle to the cross-sectional area of the wind tunnel nozzle
   g. Wheel rotation
   h. Internal flow in the model

   The SAE Standards Committee, Open Throat Wind Tunnel Adjustments had as a goal to document the knowledge of the influence of model interference on wind tunnel test results for automotive open jet wind tunnels. This document contains the following information related to this subject:

   a. Design data of open throat wind tunnels
   b. A summary of published and unpublished test data
   c. Documentation and theoretical explanation of various blockage correction procedures for automotive tests
   d. Critical evaluation of blockage correction procedures, especially in relation to other influences, such as test section geometry, position of the car, floor boundary layer, etc.
   e. Recommendation of a calibration procedure to determine the effect of blockage and other influences in each individual wind tunnel

   An initial goal of the committee, to recommend a well proven correction procedure for automotive open jet wind tunnels based on blockage theory (Figure 1), could not be established at this time. The reason is that, besides blockage, other factors, such as test section geometry, are at least as influential as pure blockage. As these influential parameters are wind tunnel specific, a general valid adjustment procedure is presently not available.

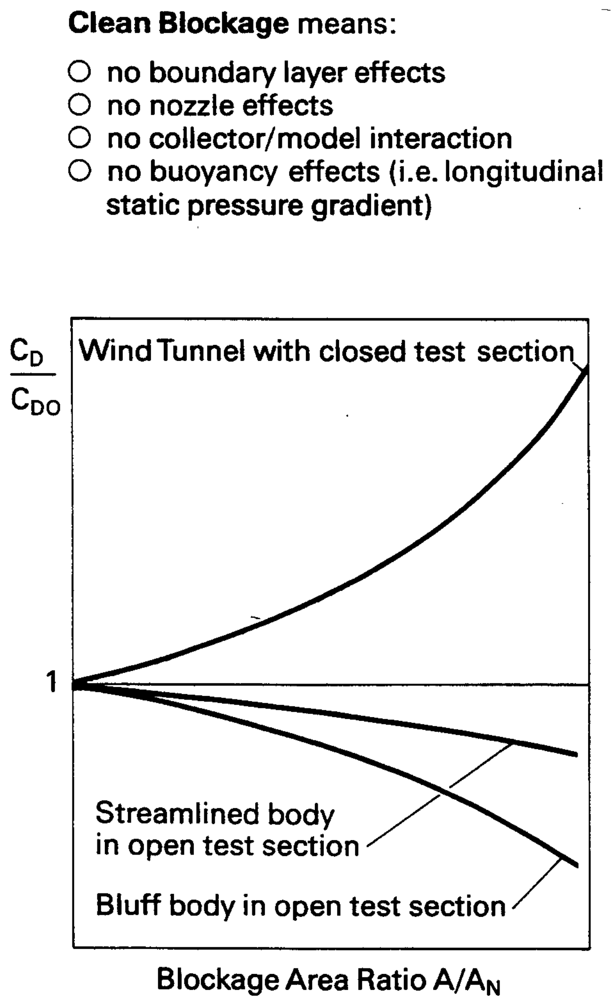

FIGURE 1—PURE MODEL SIZE INFLUENCE

2. *References*

2.1 Applicable Publications—The following publications form a part of the specification to the extent specified herein. Unless otherwise indicated the lastest revision of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

1. Ludvigsen, K.E.
Automotive Aerodynamic Research Over Past 50 Years in Germany, Great Britain, Italy, United States, and Other Countries
SAE Paper 700035, 1970
2. Buchheim, R. et al.
Comparison Tests Between Major European Automotive Wind Tunnels.
SAE Paper 800140, Detroit, 1980
3. Buchheim, R. et al.
Comparison Tests Between Major European and North American Automotive Wind Tunnels
SAE Paper 830301, Detroit, 1983

4. Cogotti, A. et al.
Comparison Test Between Some Full-Scale European Automotive Wind Tunnels - Pininfarina Reference Car
SAE Paper 800139, Detroit, 1980
5. Costelli, A. et al.
FIAT Research Center Reference Car: Correlation Tests Between Four Full Scale European Wind Tunnels and Road
SAE Paper 810187, Detroit, 1981
6. Carr, G.W., Stapleford, W.R.
Blockage Effects in Automotive Wind-Tunnel Testing
SAE Paper 860093/1986
7. Mercker, E.
General Consideration About Blockage Correction in Open Jet Wind Tunnels
SAE Subcommittee No. 9 - Communication (1987)
8. Janssen, L.J., Domeland, P., Lindener, N.
The New BMW Acoustic Wind Tunnel
Paper planned for SAE Congress, Detroit, February 1990
9. Janssen, L.J., Lindener, N., Mullenbach, P., VAGT, J.-D.
Measurement of Tunnel Speed and Static Reference Pressure in Open Jet Automotive Wind Tunnels
Paper planned for SAE Congress, Detroit, February 1990

2.1.2 OTHER PUBLICATIONS

1. Konig-Fachsenfeld, R.
Aerodynamik des Kraftfahrzeugs Umschau-Verlag, Frankfurt a.M.
2. Kramer, C. et al.
Wind Tunnels for Industrial Aerodynamics
J. Wind Engineering and Industrial Aerodynamics 16 (1984), pp 225–264
3. Lock, C.N.H.
The Interference of a Wind Tunnel on a Symmetrical Body
ARC, R & M 1275, 1929
4. Wust, W.
Verdrängungskorrektur für rechteckige Windkanäle bei verschiedenen Strahlbegrenzungen und bei exzentrischer Lage des Modells
Z. Flugwiss. 9 (1961), p. 15
5. Schulz, G.
Die Verdrängungskorrekturen in Unterschallwindkanälen und die Grenzen ihrer Anwendbarkeit
Z. Flugwiss. 20 (1972), p. 261
6. Kuchemann, D., Vandrey, F.
Zur Geschwindigkeitskorrektur in Windkanälen mit freier Meßstrecke unter besonderer Berücksichtigung des Düseneinflusses
Jahrb. 1941 der deutschen Luftfahrtforschung
7. Mercker, E.
A Blockage Correction for Automotive Testing in a Wind Tunnel With Closed Test Section
J. Wind Engineering and Industrial Aerodynamics, 22 (1986)
8. Maskell, E.
A Theory of the Blockage Effects on Bluff Bodies and Stalled Wings in a Closed Wind Tunnel
ARC, R & M 3400, 1961
9. Sachs, P.
Wind Forces in Engineering
Pergamon Press, Volume 3, 1972
10. Rogers, E.
Subsonic Wind Tunnel Wall Corrections
AGARDograph 109, 1966

11. Owen, T.B.
Measured Blockage Effects on Bluff Bodies in Closed and Open Wind Tunnels
RAE Technical Report 78151, Dec. 1978, London
12. Templin, J.T., Raimondo, S.
Experimental Evaluation of Test Section Boundary Interference Effects in Road Vehicle Tests in Wind Tunnels
6th Colloquium on Industrial Aerodynamics, June 19–21, 1985, Aachen
13. Gerhardt, H.J., KRAMER, C.
Blockierungseffekte in Windkanälen mit Bodenplatte und offener Meβstrecke Vortrag im HDT im Rahmen des Seminars
Kraftfahrzeugaerodynamik, 11/87
14. Mercker, E.
Eine Blockierungskorrektur für aerodynamische Messungen in offenen und geschlossenen Unterschallwindkanälen, Doctorate
Thesis, Dec. 1980, Berlin
15. Cooper, K.R., et al.
A Comparison of Aerodynamic Drag Measurements on Model Trucks in Closed Jet and Open Jet Wind Tunnels
6th Colloquium on Industrial Aerodynamics, June 19–21, 1985, Aachen
16. Garner, H.C., et al.
Subsonic Wind Tunnel Wall Corrections
AGARDograph 109, Oct. 1966
17. Frimberger, R., Pucher, P.
Ringversuche zur Klärung des Versperrungseinflusses kantiger Körper in Windkanälen mit offener Meβstrecke
Institut für Strömungsmechanik, TU München, Bericht 77/1
18. Regenscheit, B.
Isotherme Luftstrahlen, Verlag C.F.
Müller, Karlsruhe 1981
19. Kramer, C. et al.
Auslegung von Freistrahlmeβstrecken für Fahrzeugwindkanäle
Vortrag im HDT im Rahmen des Seminars
Aerodynamik von Kraftfahrzeugen, 11/87
20. Kramer, C., Gerhardt, H.J., Janssen, L.J.
Flow Studies of an Open Jet Wind Tunnel and Comparison With Closed and Slotted Walls
Journal of Wind Engineering and Industrial Aerodynamics, 22 (1986), 115–127
21. V. Schulz-Hausmann, F.K., Vagt, J.-D.
Influence of Test Section Length and Collector Area on Measurements in Three-Fourths Open Jet in Automotive Industry
SATA-Conference No. 23, Palo Alto, CA, 1987
22. Vagt, J.-D.
Merkmale des Porsche-Meβzentrums für Aerodynamik
Haus der Technik Tagung Nr. T-30-905-056-7, Nov. 1987
23. Mullenbach, P., Deutenbach, K.-R.
Determination of Dynamic Pressure and Reference Pressure in Automobile Wind Tunnels With Open Test Sections
8th Colloquium on Industrial Aerodynamics, Aachen, 4–7 Sept. 1989

3. ***Description of Open Jet Automotive Wind Tunnels***—For automotive applications, an open jet wind tunnel is a wind tunnel where the test section is three-fourths open and the road is represented by a level floor. For historical reasons (2.1.1 (1) and 2.1.2 (1)), open jet wind tunnels for automotive testing are used mainly in Europe. Their principal advantages are as follows:

a. Theoretically lower absolute values of blockage correction compared to closed test sections
b. Easy access to the test section

In designing open jet wind tunnels, the control of the flow quality data is a major problem. Based on the available data and the experience of the members of the committee, the flow quality data that are generally sufficient, and (in any case) achievable, in an open jet wind tunnel for automotive testing are given in Table 1.

TABLE 1—FLOW QUALITY FOR OPEN THROAT TEST SECTIONS - EXISTING MINIMUM REQUIREMENT

		Existing Minimum Requirement
Angularity in pitch	$\Delta\alpha$ (deg)	$\leq \pm 0.5$
Angularity in yaw	$\Delta\beta$ (deg)	$\leq \pm 0.5$
Uniformity of flow velocity	Δv (%)	$\leq \pm 1.0$
Turbulence intensity	Tux (%)	≤ 0.5
Pressure Level variation	Δcp (-)	< 0.01
Length of pressure level	$\Delta 1/L$ (-)	≥ 1.0 (≥ 1.5) (1)
Displacement thickness	δ^* (mm)	10% of the ground clearance

1. Some experimental results (Vagt SAE 88) suggest that for larger blockage ratios (>5% – 10%) the length of constant pressure level should be increased.

The test section geometrical parameters of various open jet wind tunnels used for full-scale automotive testing are given in Table 2. Table 3 gives the data for tunnels that are used for scale model testing. The effect of these geometrical parameters is superimposed on blockage effects in open jet wind tunnels, as will be shown later.

TABLE 2—OPEN TEST SECTION GEOMETRY OF LARGE TUNNELS (FOR FULL-SCALE TESTING)

WT Owner WT Part	Dimension	BMW AE	BMW AC	DB	FIAT	FORD	PININF.	PORSCHE	VW	IVK
Nozzle Exit Area	m^2	20.02	10.0	32.64	30.0	23.75	11.75	22.3	37.5	22.45
Nozzle Width	m	5.77	4.0	7.4	7.0	6.0	5.0	6.2	7.5	5.8
Nozzle Height	m	3.47	2.828	4.9	4.6	4.0	2.9	3.6	5.0	3.87
Nozzle Contraction Ratio	-	3.66	3.0	3.6	4.0	4.0	6.5	6.06	4.0	4.411
Test Section Length	m	10.02	9.83	10.0	10.5	10.5	8.0	13.5	10.0	9.5
T-S Surr. Bound. Width	m	10.34	13.74	14.8	12.2	15.0	9.6	12.7	17.0	15.0
T-S Surr. Bound. Height	m	5.30	5.72	7.5	10.8	8.5	4.2	6.85	13.0	8.5
Model. Ref. Point x/L (TS)	-	0.471	0.356	0.5	0.55	0.39	0.46	0.41	0.43	0.474
Collector Cross Section	m^2	22.12	22.64	47.4	40.5	29.73	17.33	42.2	44.8	26.5
Collector Width	m	6.01	5.66	8.5	7.8	6.68	6.2	8.7	8.0	6.354
Collector Height	m	3.68	4.0	6.5	5.6	4.45	3.5	4.85	5.6	4.166
Maximum Speed	m/s	50	70	70	56	51	54	64	50	75

TABLE 3—OPEN TEST SECTION GEOMETRY OF SMALL TUNNELS (FOR SCALE MODEL TESTING)

WT Owner WT Part	Dimen-sion	Aachen	Aachen	DB	DLR	DLR	DLR	FIAT	FORD	IVK	PORSCHE	VOLVO	VW
Nozzle Exit Area	m^2	1.0	2.69	1.64	8.61	8.1	1.53	4.0	8.64	1.654	1.4	4.125	6.0
Nozzle Width	m	1.1	2.0	1.5	3.25	3.0	1.3	2.4	3.65	1.575	1.55	2.4	3.0
Nozzle Height	m	1.1	1.4	1.096	2.65	2.7	1.18	1.7	2.44	1.05	0.9	1.73	2.0
Nozzle Contraction Ratio	-	3.3	2.57	6.0	5.6	5.44	4.91	7.0	11.0	4.988	6.06	6.25	6.0
Test Section Length	m	1.83	4.0	2.8	6.0	6.0	2.48	4.0	6.1	2.578	3.38	8.82	6.0
T-S Surr. Bound. Width	m	8.65	5.74	5.15	16.4	8.0	4.8	5.7	15.0	6.85	3.42	6.06	6.5
T-S Surr. Bound. Height	m	4.0	2.85	2.35	9.5	5.9	5.2	6.4	8.5	3.39	1.84	4.0	4.0
Model Ref. Point x/L (TS)	-	0.55	0.38	0.46	0.43	0.48	0.5	0.4	0.41	0.474	0.41	0.283	0.42
Collector Cross Section	m^2	1.45	4.2	2.3	10.26	17.0	1.84	7.6	11.33	1.921	2.66	12.25	6.9
Collector Width	m	1.32	2.4	1.85	3.67	5.15	1.5	3.3	4.12	1.712	2.18	3.5	3.0
Collector Height	m	1.32	1.7	1.3	2.8	3.3	1.28	2.3	2.75	1.122	1.22	3.5	2.3
Maximum Speed	m/s	42	38	65	75	65	55	70	84	80	64	53	50

The data given in Tables 1, 2, and 3 are also an indication of the range of flow quality and test section design data for which the following discussions about blockage corrections are valid. The data are based on the present experience of the committee members. The definition of the various values is as follows:

a. Standard Control Box Test Volume: All flow quality parameters will be related to a standard control box test volume. The test vollume size is defined as:

   Length = 100% of typical vehicle length
   Height = 100% of typical vehicle height
   Width = 100% of typical vehicle width for nonyawed conditions
   = 200% of typical vehicle width for yawed conditions