BACKGROUND ACOUSTIC DISTURBANCES IN HIGH SPEED WIND TUNNELS

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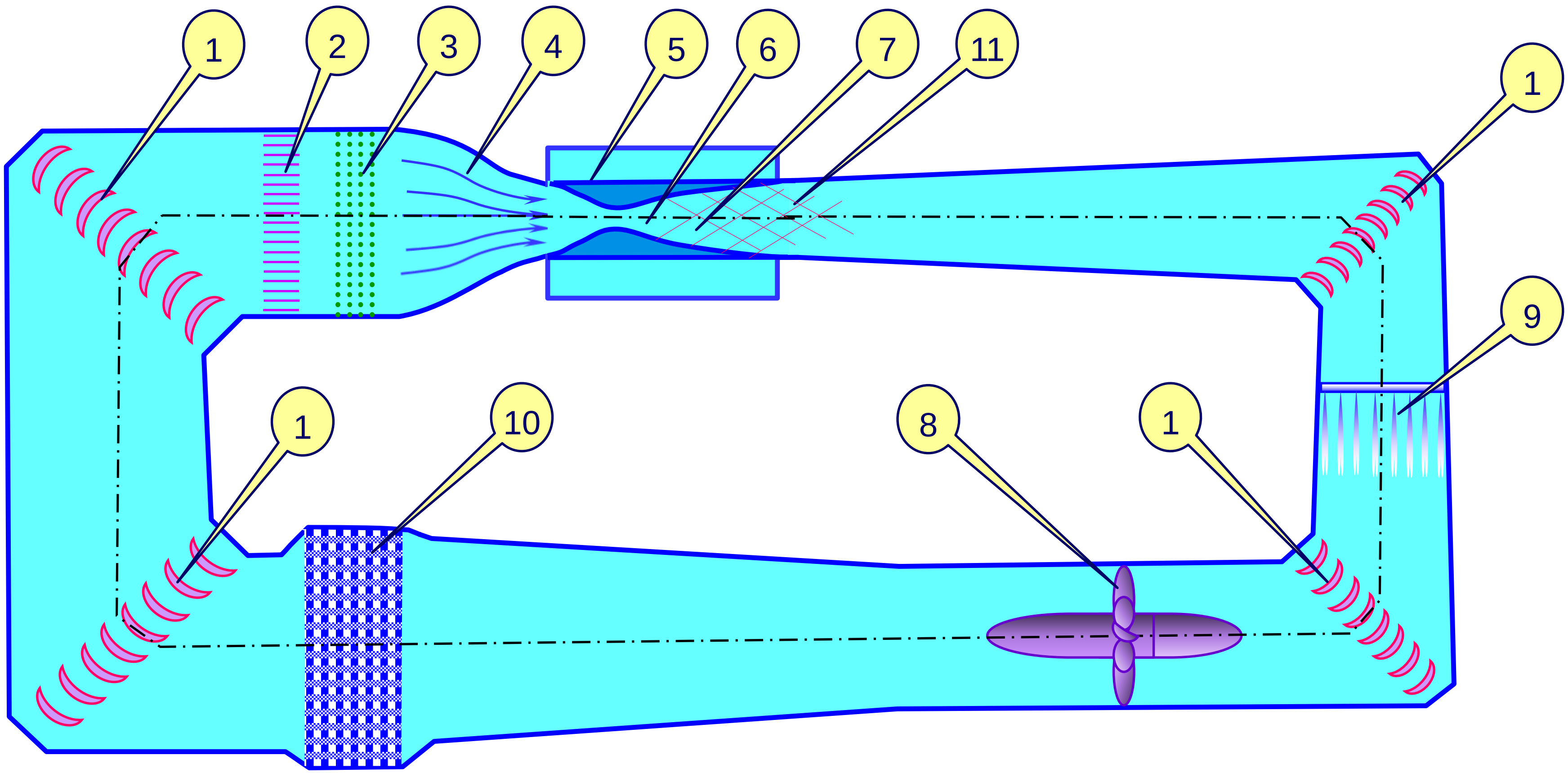
Flow disturbances in test sections of wind tunnels are important due to influence on

- boundary layer transition;
- flow separation;
- aerodynamic characteristics, etc.

Very often experimental results obtained at the same flow conditions but in different facilities differs a lot.

Therefore, when using experimental data as test cases for verification of calculations, it is necessary do not forget about this.

Sources of flow disturbances



1. Turning blades
2. Honeycomb
3. Screens
4. Contraction
5. Perforation
6. Boundary layer
7. Roughness
8. Fan
9. Injection
10. Cooling system

....

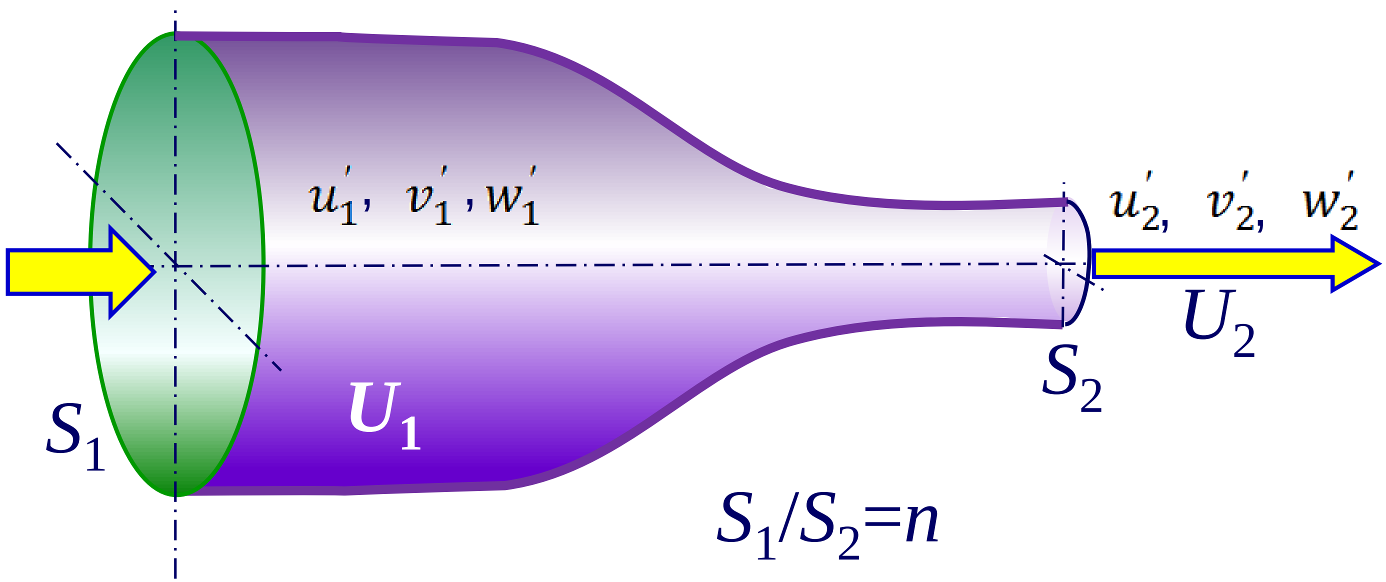
Mach waves

- ☞ **TURBULENCE;**
- ☞ **TEMPERATURE INHOMOGENETIES;**
- ☞ **ACOUSTICS**

- ☞ TURBULENCE;
- ☞ TEMPERATURE INHOMOGENETIES;
- ☞ ACOUSTICS

TURBULENCE

Contraction



$$\frac{u'_1/U_1}{u'_2/U_2} = n^{3/2}$$

$$\frac{v'_1/U_1}{v'_2/U_2} = n^{1/2}$$

$$\frac{w'_1/U_1}{w'_2/U_2} = n^{1/2}$$

☞ **TURBULENCE;**

☞ **TEMPERATURE INHOMOGENETIES;**

☞ **ACOUSTICS**

TEMPERATURE INHOMOGENETIES

is important for:

- **CLOSED CIRCUIT WIND TUNNELS;**
- **CRYOGENIC WIND TUNNELS;**
- **WIND TUNNELS WITH HEATERS**

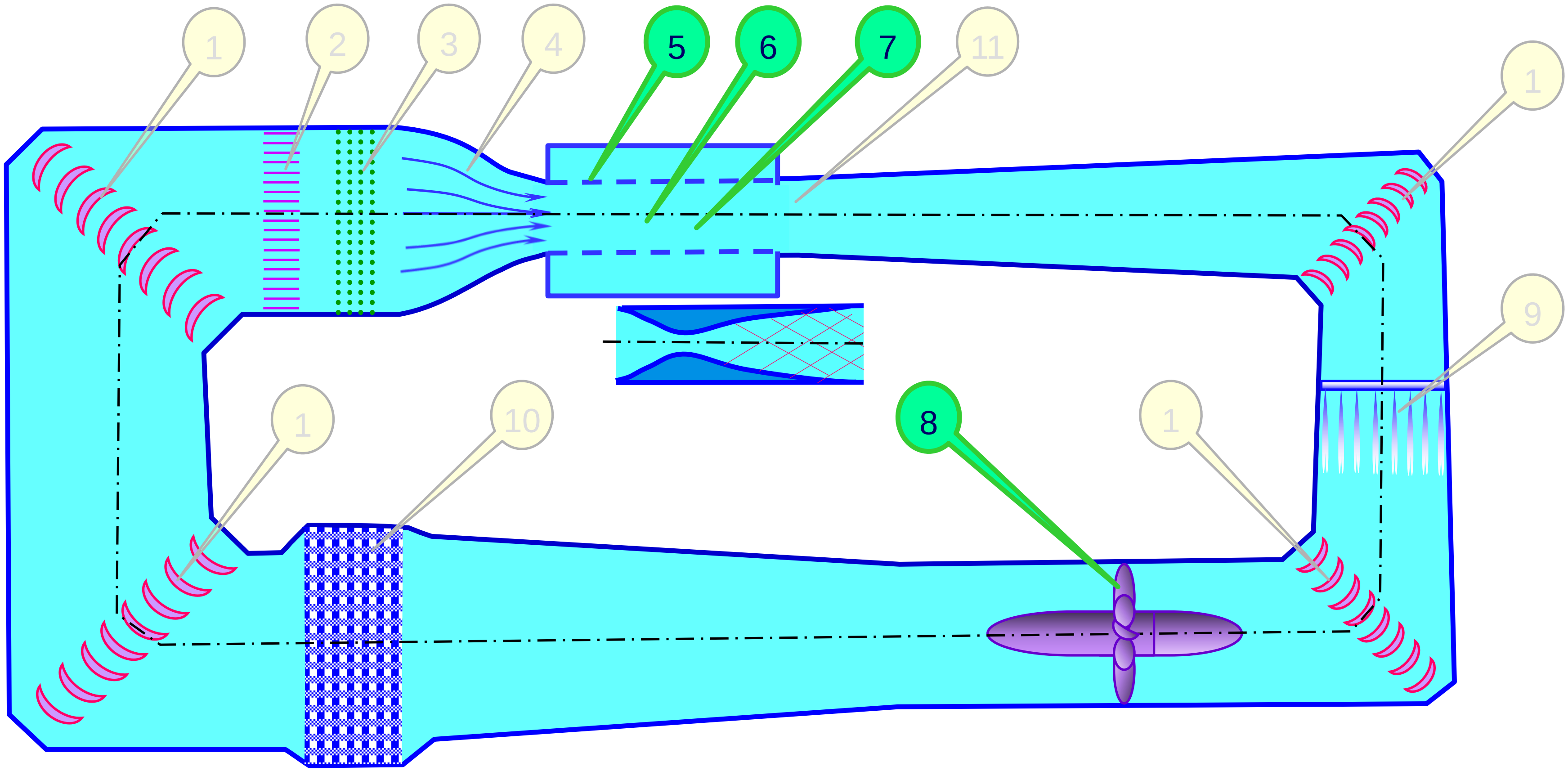
The temperature spottiness can be reduced due to thermal conductivity, however because of very short time of the flow passage through the contraction the effect is too small.

The contribution of the temperature inhomogeneity is negligible in ordinary wind tunnels.

All ordinary transonic and supersonic wind tunnels are low turbulent wind tunnels

- ☞ **TURBULENCE;**
- ☞ **TEMPERATURE INHOMOGENETIES;**
- ☞ **ACOUSTICS**

ACOUSTICS



5. Perforation
6. Boundary layer
7. Roughness
8. Fan

Mach waves

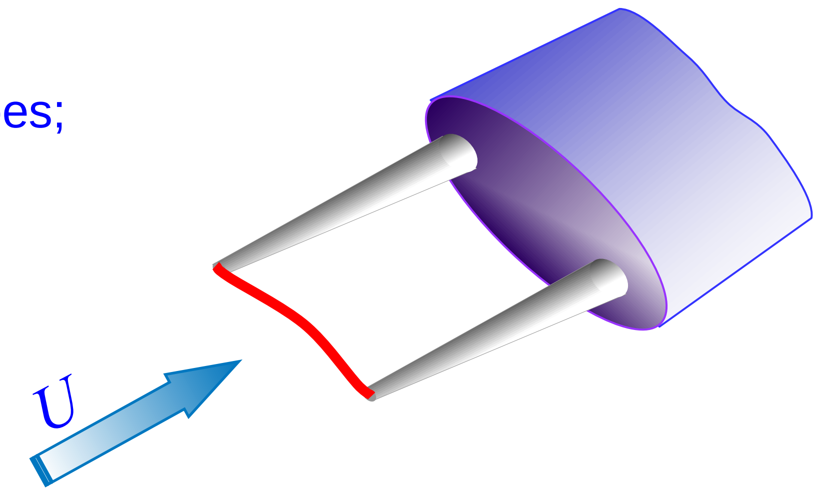
Hot-wire

Advantages:

- local measurements;
- high resolution and frequency range;
- all types of fluctuations can be measured;
- . . . .

Disadvantages :

- needs moving flow;
- possible damage of probes;
- . . . .



$$\boxed{\frac{e'}{e} = \pm\left(F\frac{m'}{m} - G\frac{T_0'}{T_0}\right)}$$

$$(m, T_0) \longrightarrow (u, \rho, T)$$

F – probe sensitivity to mass flow

G – probe sensitivity to total temperature

$$m = \rho u$$

$$T_0 = T\left(1 + \frac{\gamma - 1}{2}\mathrm{M}^2\right) = T + \frac{u^2}{2c_p}$$

$$\frac{m'}{m} = \frac{\rho'}{\rho} + \frac{u'}{u}$$

$$\frac{T_0'}{T_0} = \alpha\frac{T'}{T} + \beta\frac{u'}{u}$$

$$\alpha = \frac{T}{T_0} = \left(1 + \frac{\gamma - 1}{2}\mathrm{M}^2\right)^{-1} \qquad \beta = 2(1 - \alpha)$$

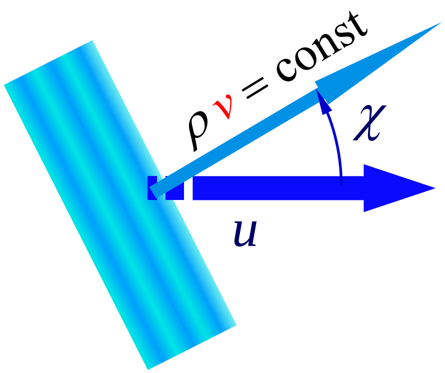
$$r = \frac{F}{G}$$

$$\boxed{\frac{e'}{eG} = \left[r\left(\frac{\rho'}{\rho} + \frac{u'}{u}\right) - \alpha\left(\frac{T'}{T}\right) - \beta\left(\frac{u'}{u}\right)\right]}$$

For acoustic wave

$$\boxed{\frac{e'}{eG} = \left[r\left(\frac{\rho'}{\rho} + \frac{u'}{u}\right) - \alpha\left(\frac{T'}{T}\right) - \beta\left(\frac{u'}{u}\right)\right]}$$

$$\frac{p}{\rho^{\gamma}} = \mathrm{const} \qquad \frac{p}{\rho} = \Re T$$



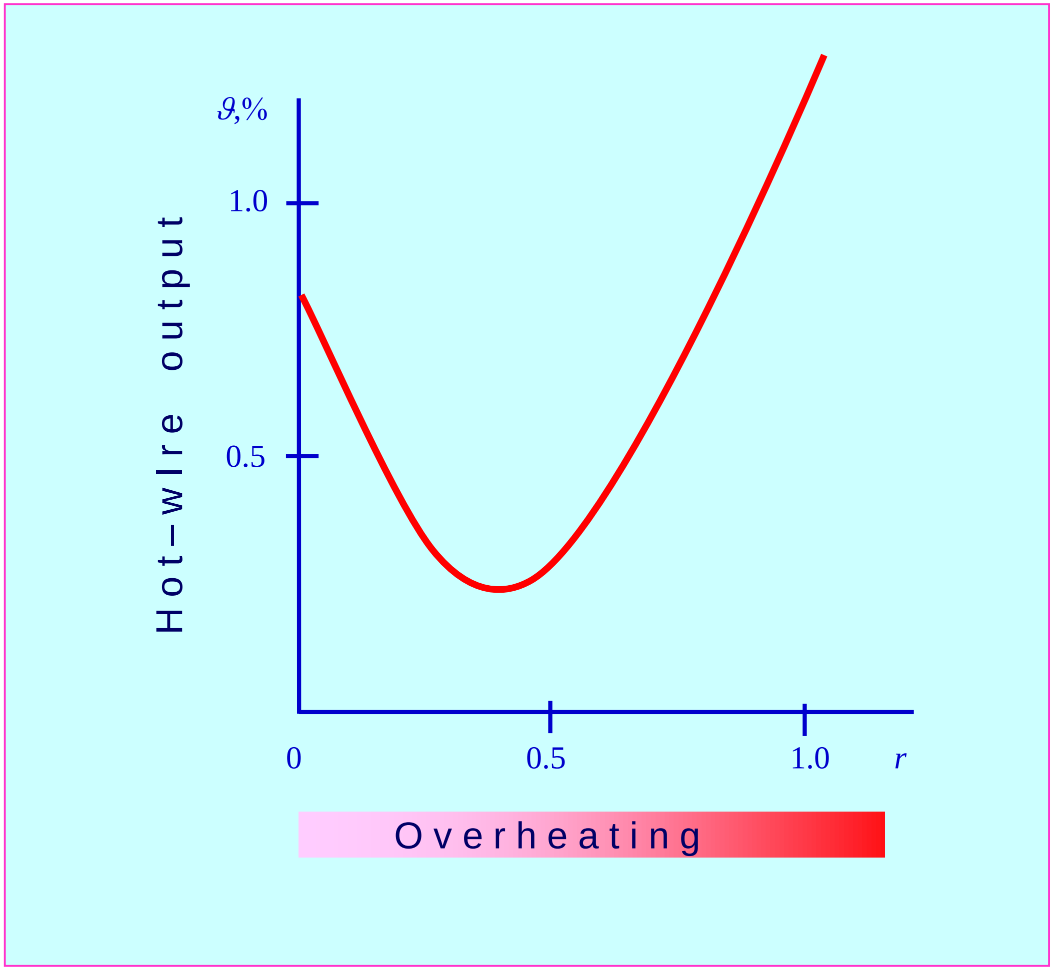
$$\frac{\rho'}{\rho} = \frac{1}{\gamma}\frac{p'}{p} \qquad \frac{p'}{p} = \frac{\rho'}{\rho} + \frac{T'}{T} \qquad \frac{T'}{T} = \frac{\gamma - 1}{\gamma}\frac{p'}{p}$$

$$\frac{\rho'}{\rho} = -\frac{v'}{a} \qquad \frac{1}{\gamma\,\mathrm{M}}\frac{p'}{p} = -\frac{v'}{u} \qquad -\frac{u'}{u} = \frac{\cos\chi}{\mathrm{M}}\frac{p'}{\gamma p}$$

$$\vartheta' = \frac{e'}{eG}$$

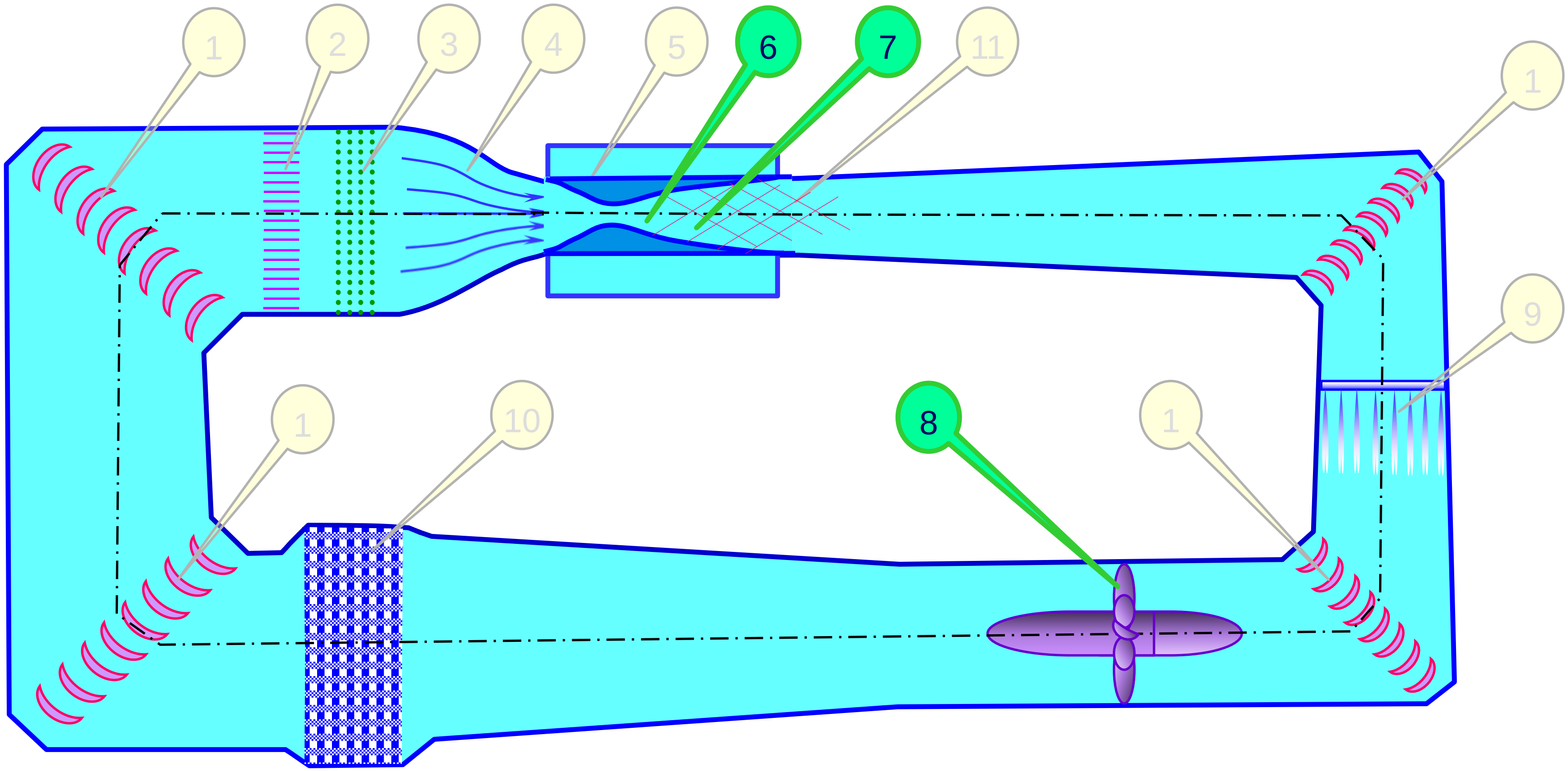
$$\boxed{\vartheta = \frac{<p>}{\gamma}\left[\alpha(\gamma - 1)(1 + \mathrm{M}\cos\chi) - r\left(1 + \frac{\cos\chi}{\mathrm{M}}\right)\right]}$$

Fluctuation Diagram



Supersonic flow velocities
(acoustics)

ACOUSTICS

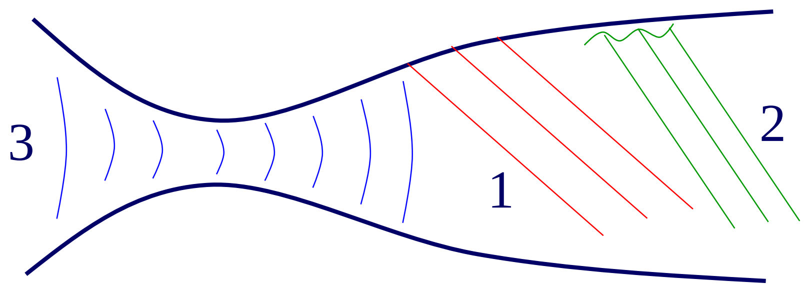


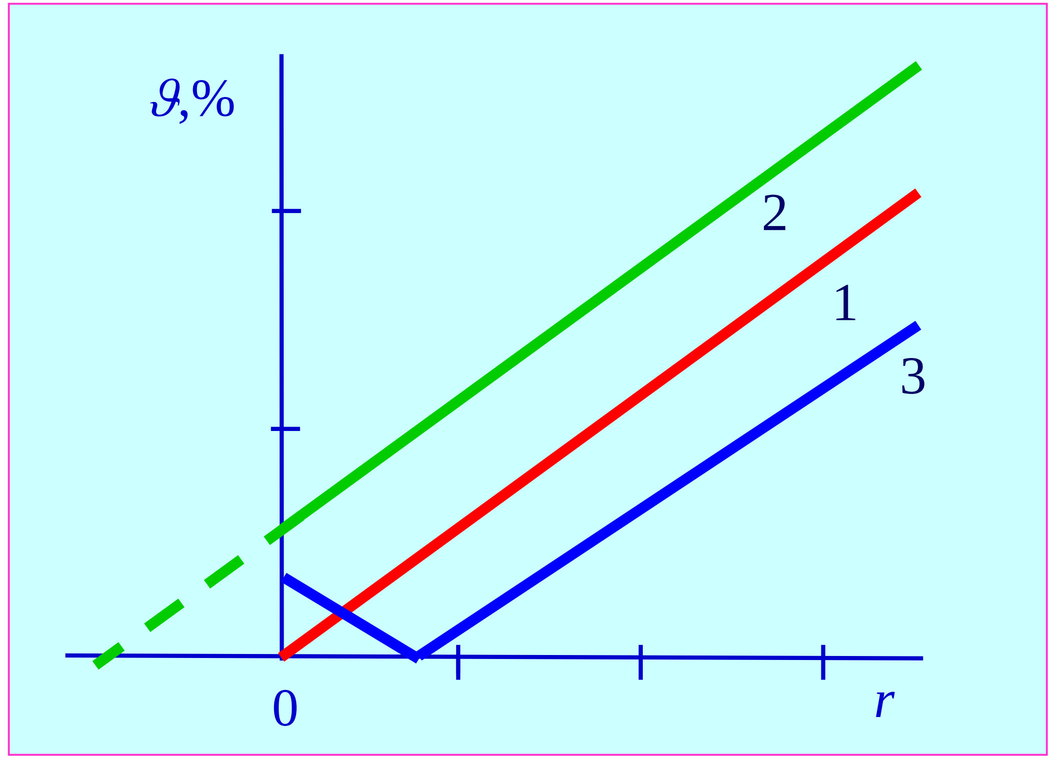
~~5. Perforation~~

6. Boundary layer
7. Roughness
8. Fan

Mach waves

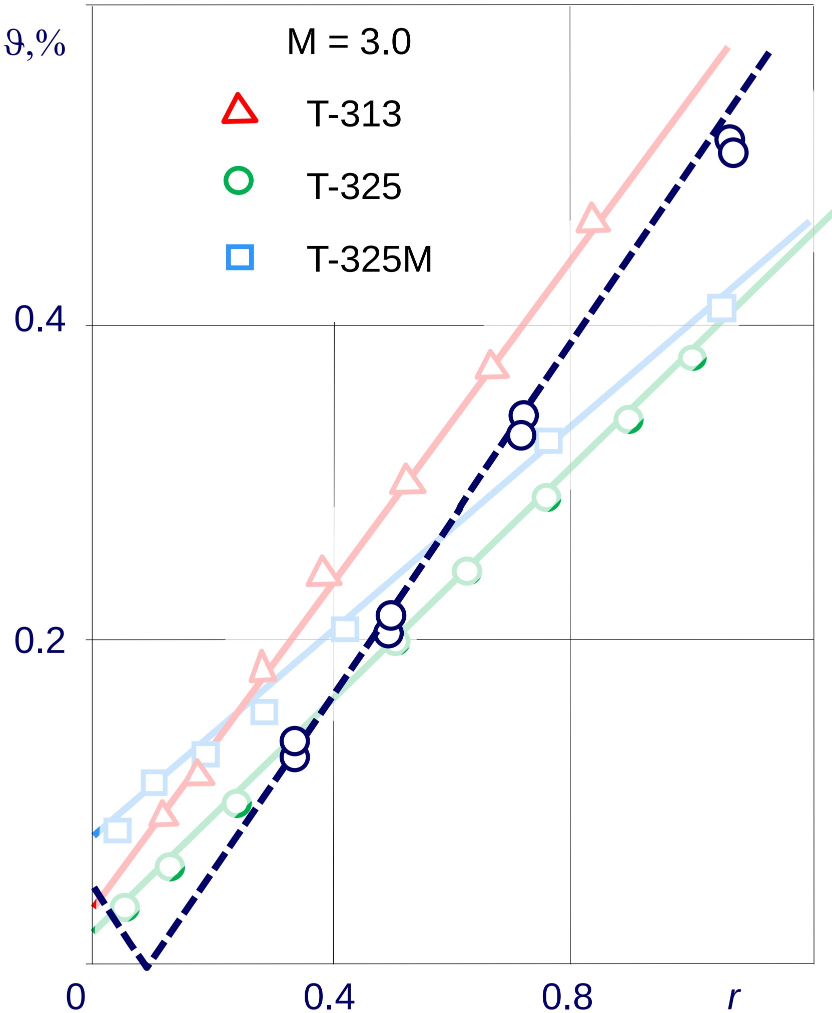
$$\vartheta = \frac{<p>}{\gamma}\left[\alpha(\gamma-1)(1+\mathrm{M}\cos\chi) - r\left(1+\frac{\cos\chi}{\mathrm{M}}\right)\right]$$



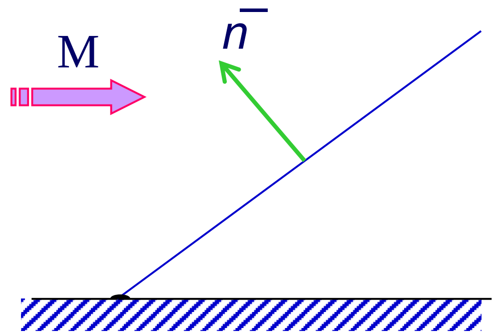


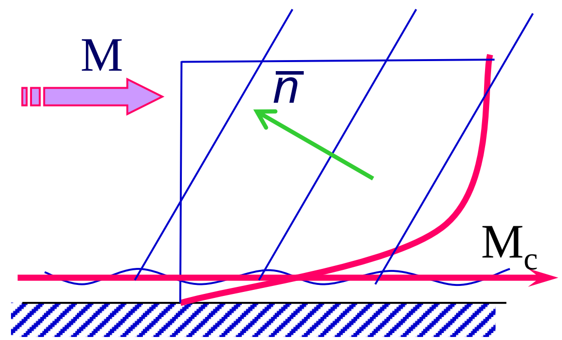
1. $r_0 = 0$: Stationary Mach waves (generated by roughness), $\sin\alpha = 1/\mathrm{M}$;
2. $r_0 < 0$: Moving Mach waves (generated by boundary layers);
3. $r_0 > 0$: Moving acoustic waves (generated before the nozzle throat)

Acoustic disturbances in supersonic ITAM wind tunnels



	<m>, %	<p>, %	<u>, %	c/u	α
T-313	0.51	0.60	0.09	0.26	27°
T-325	0.35	0.43	0.08	0.40	34°
T-325M	0.30	0.41	0.11	0.58	53°





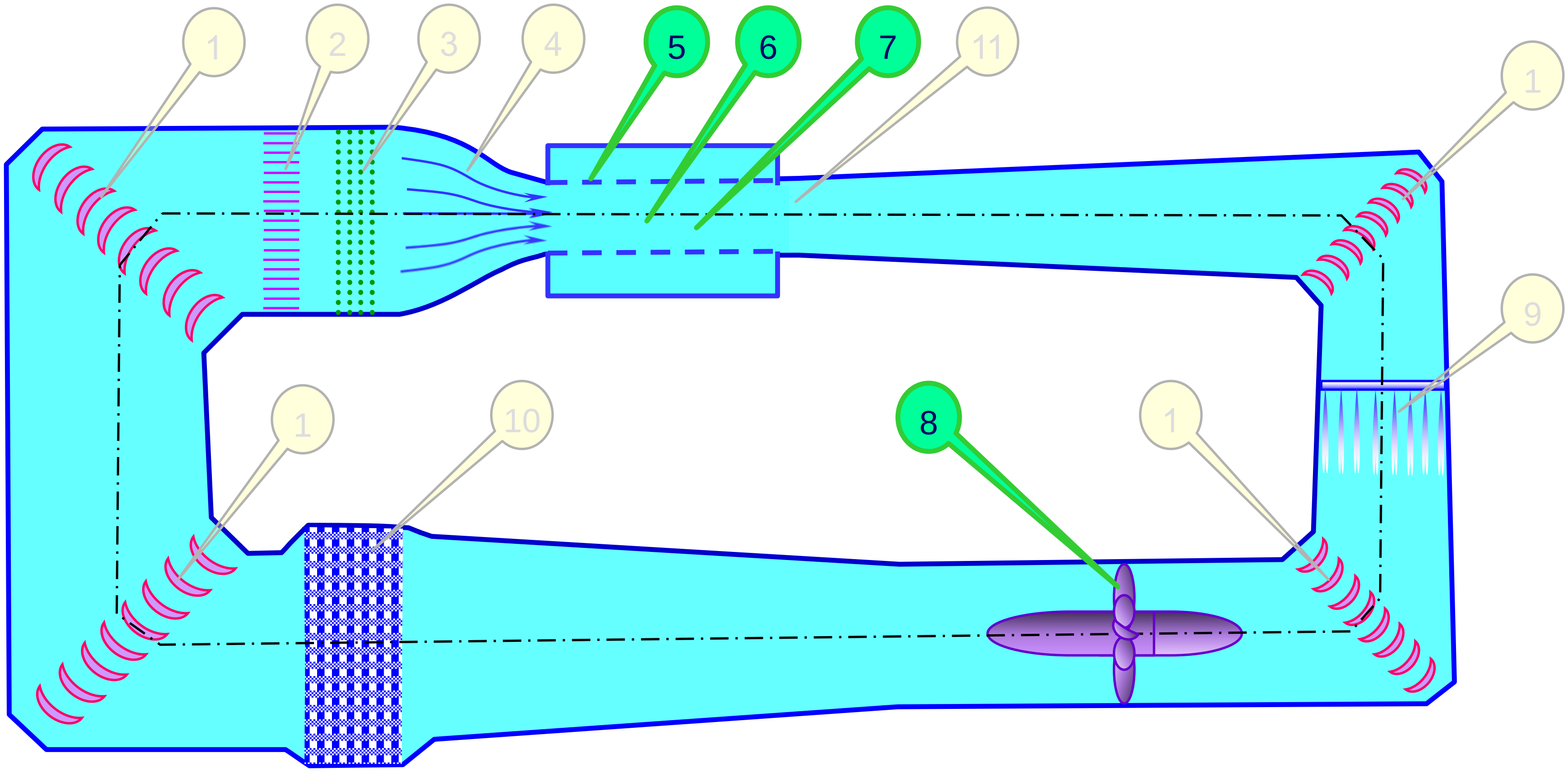
$\Delta M = (M - M_c) > 1$

Hot-wire measurements of background disturbances in test sections of supersonic wind tunnels demonstrate prevailing acoustics as the main type of the flow fluctuations

Transonic flow velocities

(acoustics)

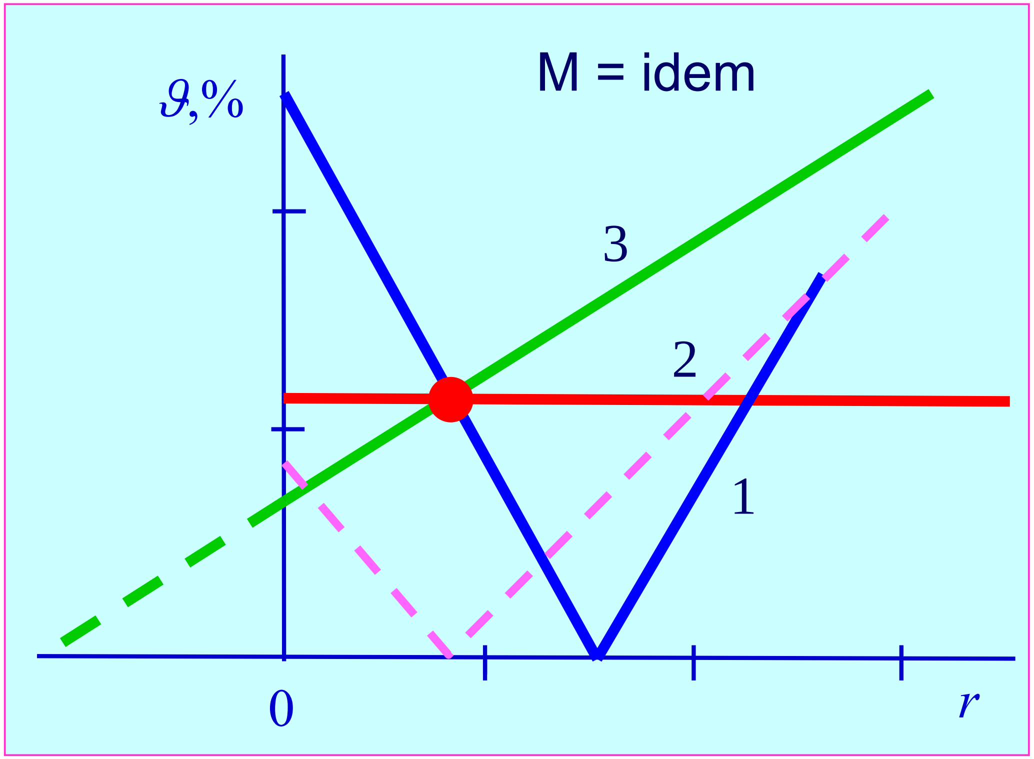
ACOUSTICS



5. Perforation
6. Boundary layer
7. Roughness
8. Fan

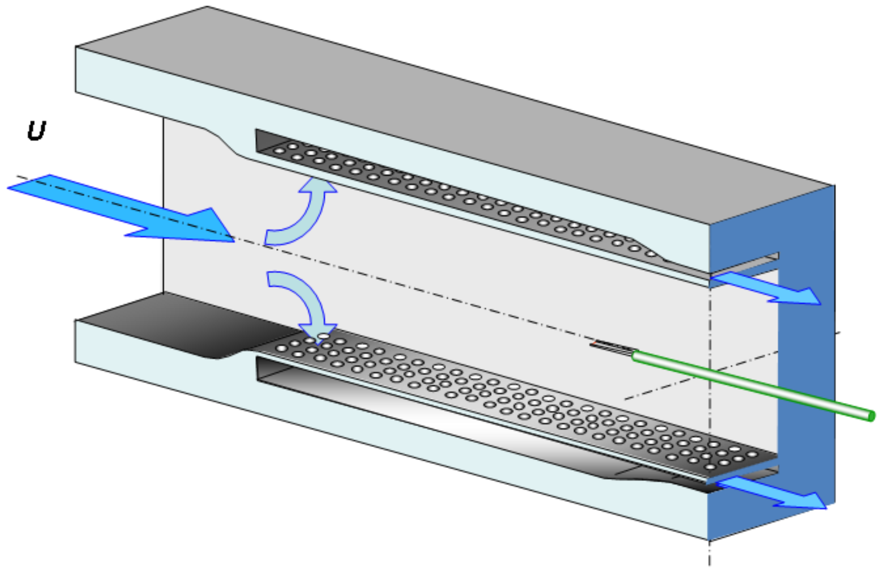
Subsonic flow velocities

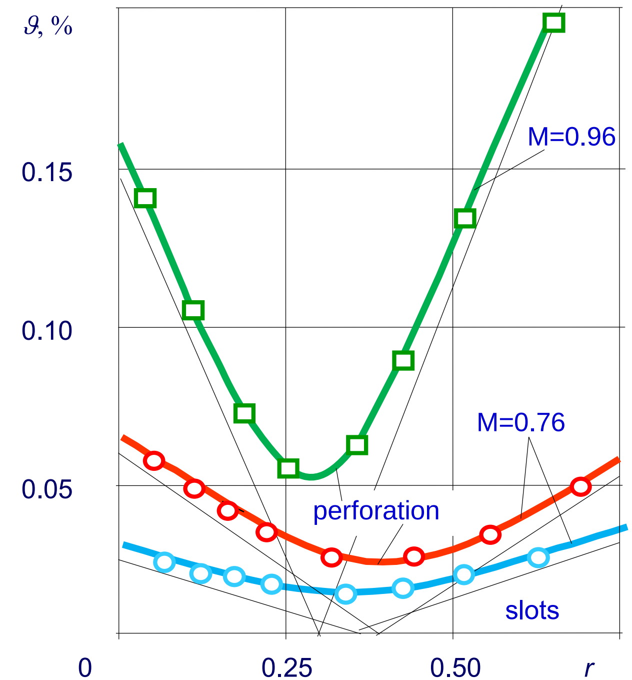
$$\vartheta = \frac{< p >}{\gamma}\left[\alpha(\gamma - 1)(1 + \mathrm{M}\cos\chi) - r\left(1 + \frac{\cos\chi}{\mathrm{M}}\right)\right]$$

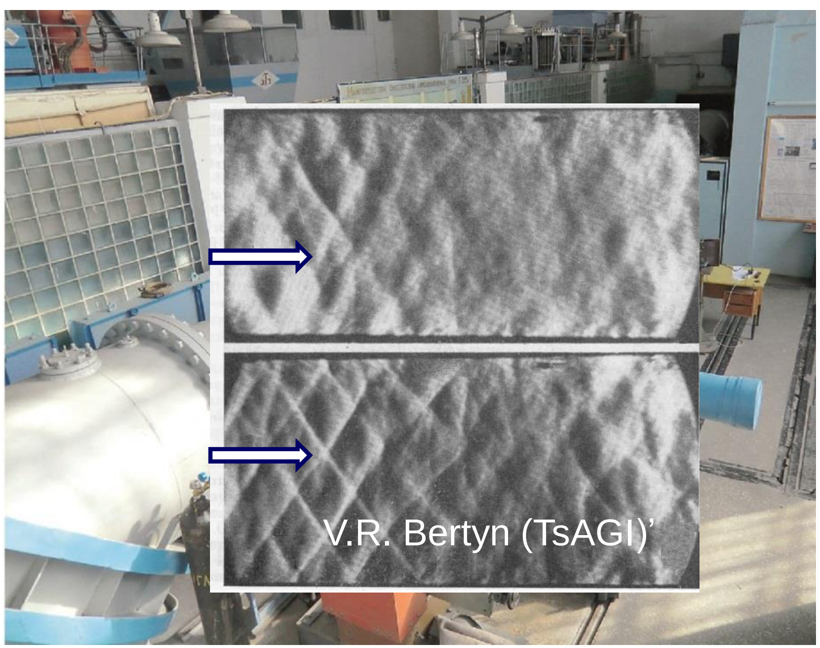


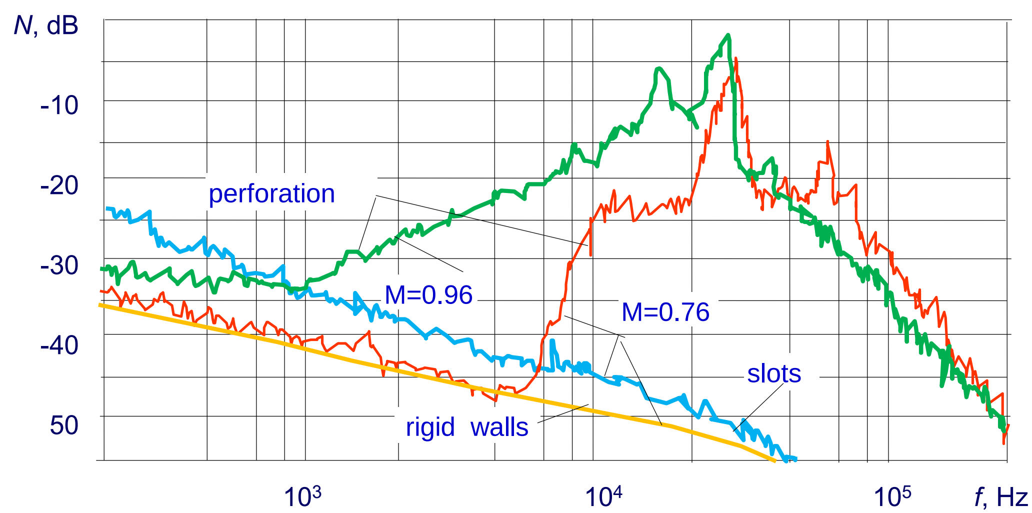
1. $r_0 > 0$ $0° \le \chi < \arccos(\text{-M})$;
2. $r_0 = \infty$ $\chi = \arccos(\text{-M})$;
3. $r_0 < 0$ $\arccos(\text{-M}) < \chi \le 180°$

T-325 ITAM SB RAS

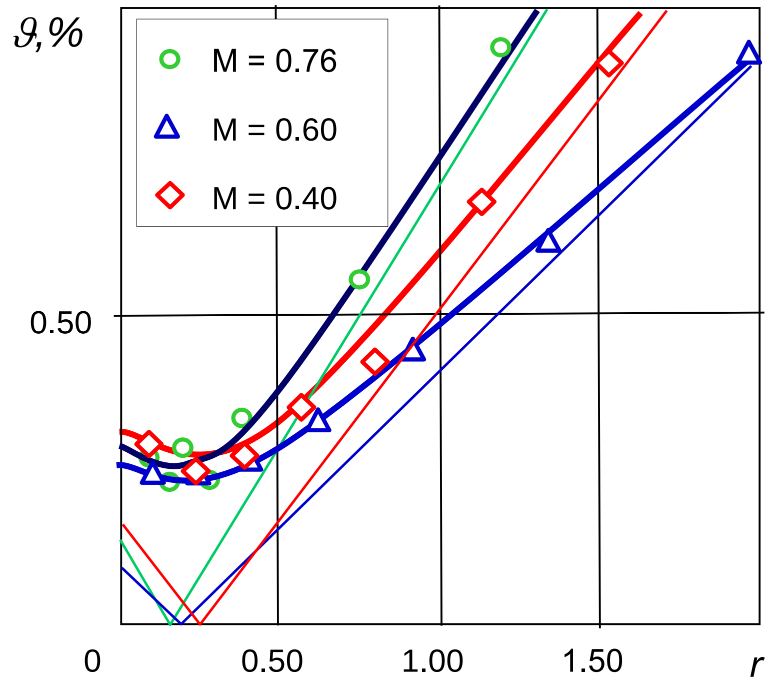






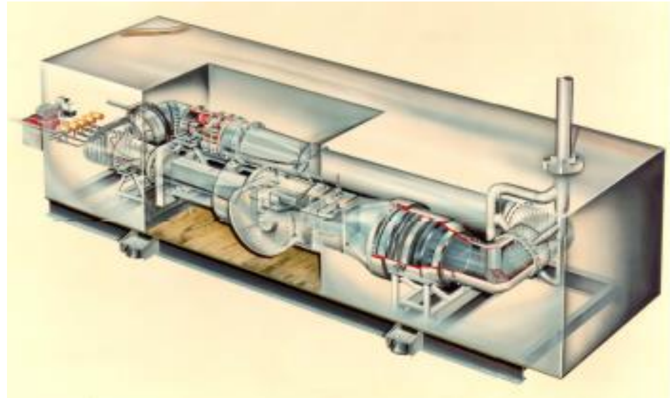


Fluctuations in test section of TWT (Taiwan, ASTRC NCKU)



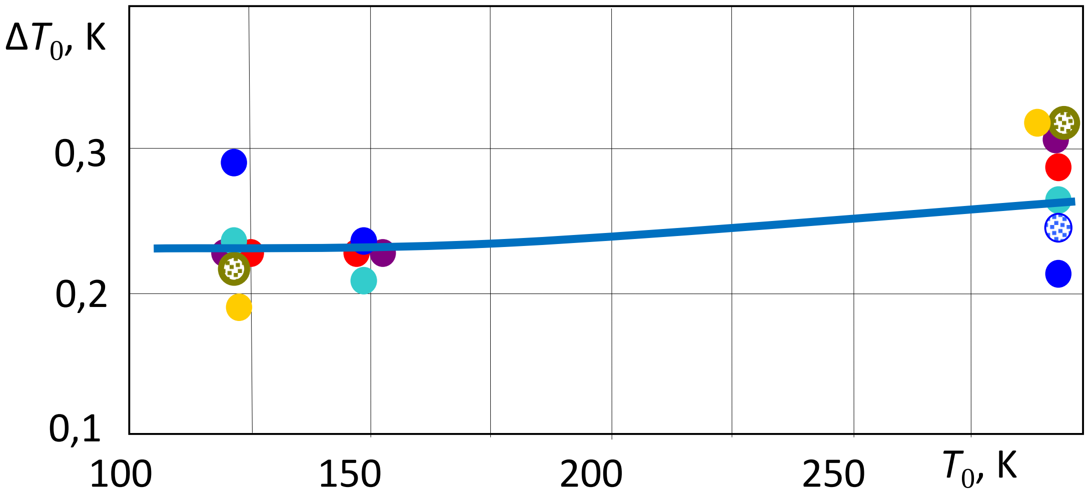
M	<m>, %	R_{mT_o}	<T_0>, %	r_{min}
0.76	0.42	0.48	0.15	0.17
0.60	0.25	0.35	0.13	0.18
0.40	0.34	0.49	0.16	0.22

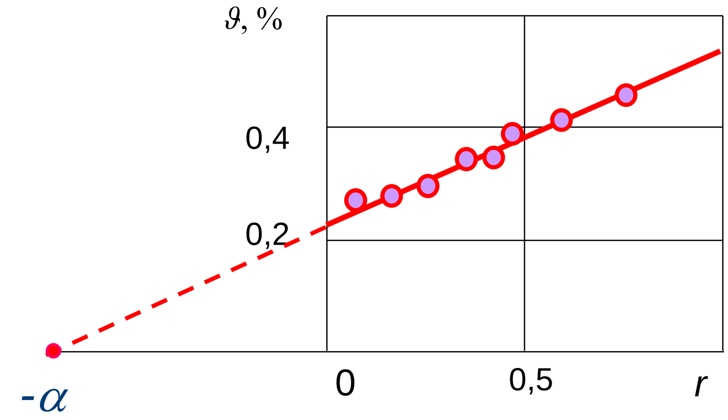
Cryogenic Transonic Wind Tunnel (Cologne, Germany)

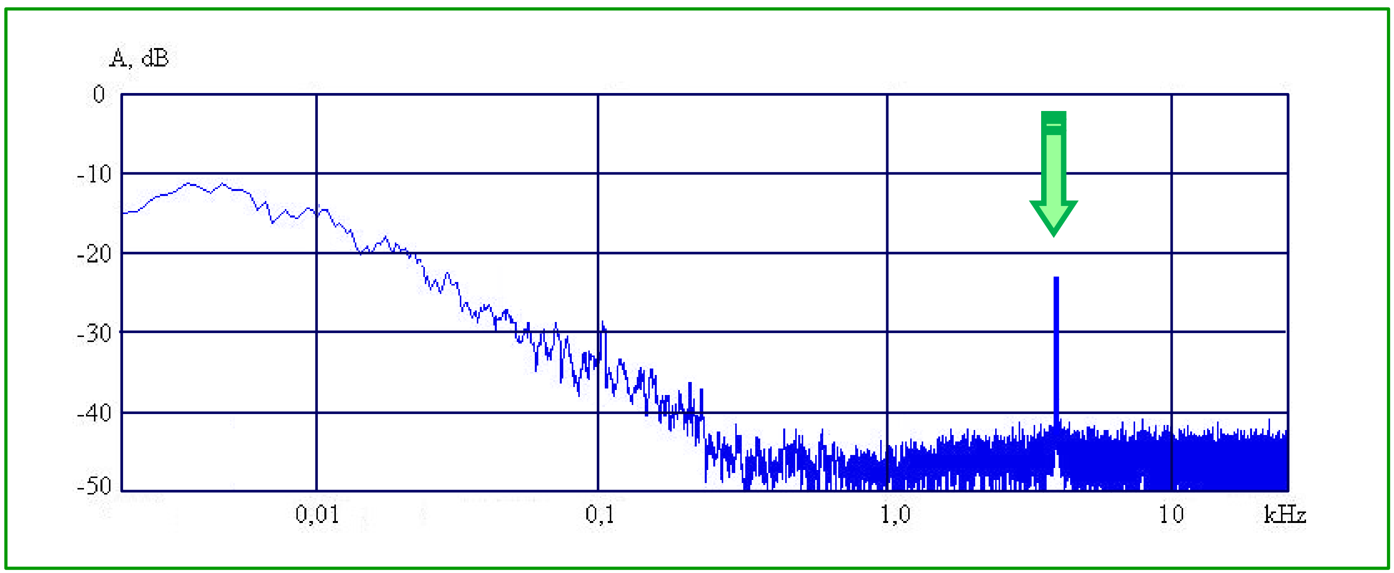


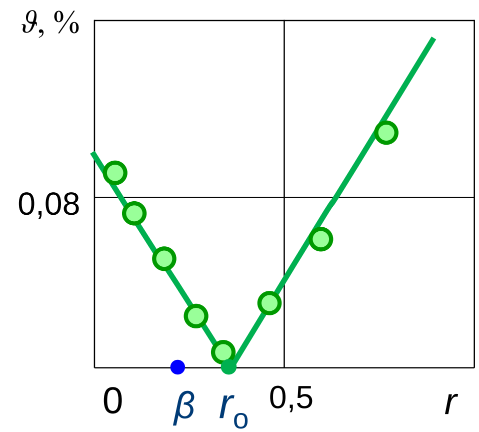
p_0	T_0	$\mathbf{Re}_1.10^{-6}$ m^{-1} $\langle m\rangle/\langle T_0\rangle$, %						
M		0.2	0.3	0.4	0.5	0.6	0.7	0.8
1.25	290	6.1 0.082/0.08	8.4 0.13/0.09	10.8 0.11/0.10	12.9 0.15/0.13	14.6 0.12/0.12	16.3 0.14/0.13	17.5 0.11/0.11
2.35	290	11.3 0.06/0.06		20.4 0.12/0.10		28.0 0.10/0.10		32.8 0.12/0.08
1.25	150	14.8 0.24/0.18		26.1 0.21/0.15		35.9 0.22/0.17		41.8 0.26/0.16
3.11	290	15.3 0.06/0.06		26.6 0.07/0.07		36.3 0.10/0.10		43.6 0.14/0.16
1.25	120	20.5 0.29/0.21	-	38.2 0.30/0.19	44.8 0.30/0.20	52.4 0.31/0.20	57.9 0.31/0.19	62.0 0,32/0,17
2.15	150	26.0 0.23/0.12		46.0 0.21/0.11		64.0 0.21/0.12		78.2 0.26/0.11
2.8	150	33.7 0.21/0.11		60.8 0.20/0.10		83.6 0.23/0.10		100.2 0.29/0.12
2.5	120	-		76.5 0.25/0.12		104.4 0.22/0.12		130.0 0.24/0.10

Fluctuations in test section of PETW (Cologne, Germany)









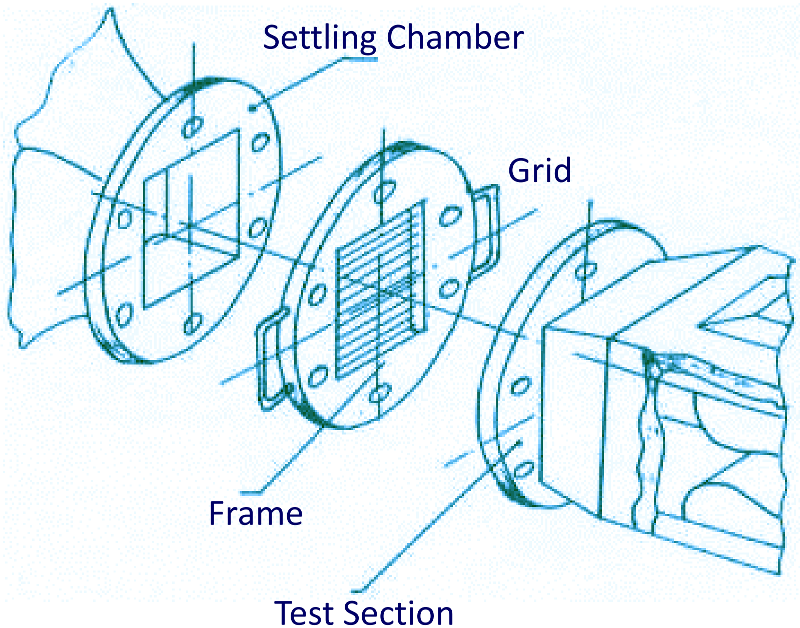
Hot-wire measurements of background disturbances in ventilated test sections of ordinary transonic wind tunnels demonstrate prevailing acoustics generated by perforations or slots as the main type of the flow fluctuations

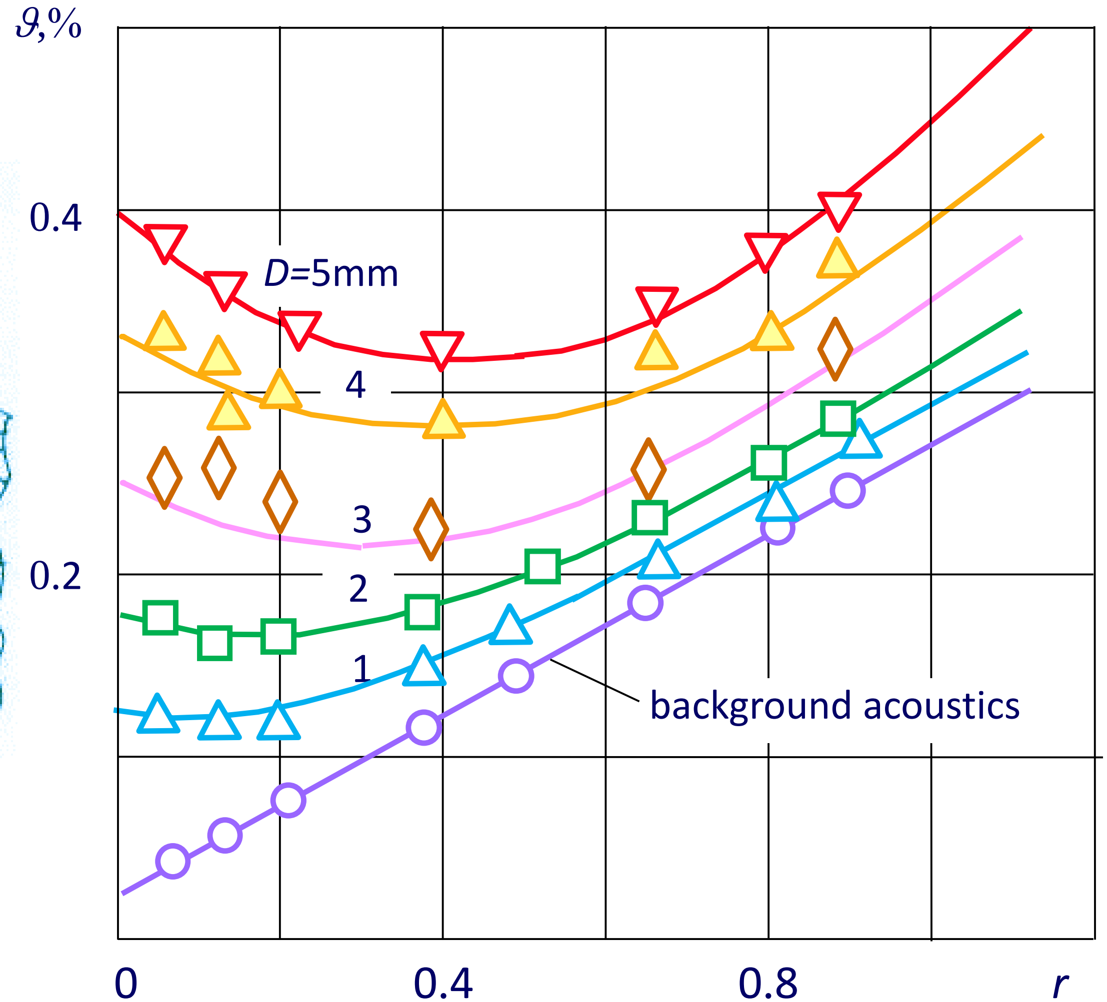
All transonic and supersonic wind tunnels are

low turbulent wind tunnels,

BUT NOT QUIET!!!

Thank you for your attention!





$\langle m \rangle_{\Sigma}$, %	0.49
$\langle T_0 \rangle_{\Sigma}$, %	0.40
Turbulence $\langle u \rangle$, %	0.38