ICSV13 - Vienna
The Thirteenth International Congress on Sound and Vibration
Vienna, Austria, July 2-6, 2006

HORIZONS FOR AN AEROACOUSTIC RESEARCH PLATFORM BY EUROPEAN CO-OPERATION IN ROMANIA

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Abstract

The team of researchers at the “Aerospace Sciences Department “Elie Carafoli” in U.P.B. presents its international initiative of establishing the HARPER laboratory, consisting of a new type of an aeroacoustic wind tunnel for advanced experiments. Far more extended than a specific noise research facility, the proposed platform is intended to exploit the solar energy driven system for extended environmental studies, up to the hydrogen production and storage or electricity production. International partners are invited to join the HARPER program.

INTRODUCTION

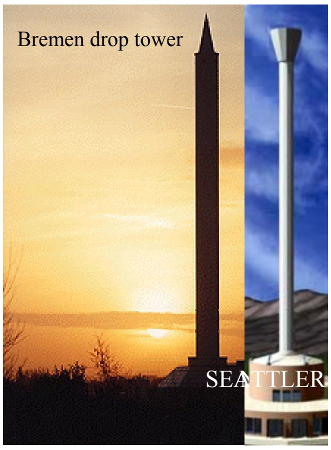
The destination of the facility is to allow the elaboration of numerical simulation activities and laboratory experiments in new and promising zones of aeroacoustics, considered as fruitful for new, emerging technologies, particularly related to aerodynamic noise suppression. The laboratory will consist of four complementary branches, namely the gravitational draught for aeroacoustics and infra-turbulence aerodynamics (GDA), solar energy heating (SEH), space structures and orbital surveillance for environmental management (SOS) and gravitational oscillator studies (GOS). Each branch accommodates a larger number of specific activities (s. Fig. 6).

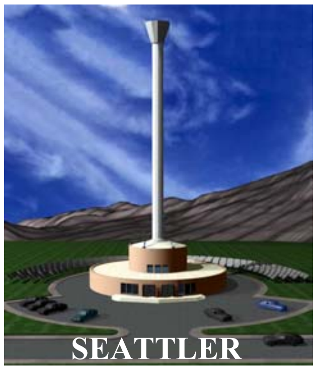
At least three European research priorities are addressed: (1) noise reduction in aerospace engines and gas turbine engines in general, (2) renewable energy with the genuine combination of solar and gravitation energies and (3) Space. The first of those addressed priorities is related to the SEATTLER aeroacoustic facility.

In more detail, the objectives of the investment refer to the creation of foundations for a complex laboratory dedicated to advanced research, under Euro-Atlantic partnership, where the central facility consists of a new type of aeroacoustic wind tunnel with zero eigen-noise of the drivers and solar energy activation. The installation is here first presented under the name SEATTLER.

SEATTLER FIRST HITS

The SEATTLER **S&T objectives** are to create an innovative, non-mechanical air accelerator with double application: as an infra-turbulence, zero driving noise acoustic wind tunnel and as a cheap solar radiation, direct action electric power plant. The first, **wind-tunnel** application, means that noise of industrial fans and especially of aircraft engines will be ideally studied and means of suppression found, at a yet unattained level due to its zero noise. The second one claims a small area alternative to the SB GmbH Solar Tower power plant that uses a very large greenhouse solar collector. With its reduced area collector and high radiation temperature, the SEATTLER solar energy tower ends in a cheaper and totally ecological manner of electricity production. Regarding the SEATTLER tunnel, the crucial progress is the complete removal of all moving parts and consequently of all driving noise sources. Named SEATTLER from ***S****olar* ***E****nergy* ***A****ctuator for* ***T****all* ***T****ower* ***L****ow-cost* ***E****lectricity* ***R****esearch*, it allows the noise of the flowing air be definitely perceived. The new tool will address the area of both fundamental and industrial research for noise protection of the environment and especially noise reduction in aeronautics, as desired by the ACARE-2020 project. The avenue towards environment-friendly aircraft engines will thus be cleaned. Besides the obvious acoustical quality of the rig, its construction is by far much simpler and far less expensive than of any other existing noise test facility. It has a vertical, small space consuming, lightweight design, to be easily incorporated amidst other or twinned to other existing facilities. It is possible to accommodate it, for example, near the well-known Bremen University Drop Tower (photo), or directly side-added to such an existing tall building. A height of the SEATTLER tunnel of 70 meters could attract air speeds of more than 50 m/s in the test chamber. At the base of the vertical exhauster (above) a test chamber building is accommodated. Neither noise nor vibrations will be sent by SEATTLER to the surroundings, offering in addition a much higher safety-level in operation also. Tinny noise reduction effects will become accessible and new standards in aeroacoustics emerge, with major benefits for noise investigations on turbo-engine individual parts. Because all existing facilities are propelled by fan type





mechanical driving equipment, they inevitably produce the well-known *eigen-noise*: part from the driving equipment and part from the flow of air in the very tunnel (Fig). This behavior highly worsens the investigation and sensible progress could only be made when the eigen-noise of the wind tunnel is either drastically reduced or completely suppressed, as in the case of the **SEATTLER** solution. The current large-scale electrical fans, despite some recently made progress, manifest a residual level of eigen-noise, while SEATTLER will be free of any driving-equipment eigen-noise (see table below).

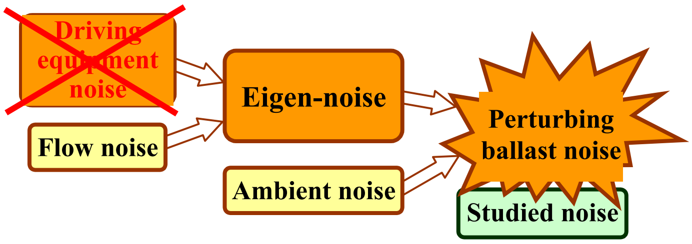


Table 1. Comparative outlook of low noise tunnels.

Facility owner	Wind Tunnel Type	Test Section (m)	Speed Range (Mach No.)	Turbulence/ /Eigen-noise	Reynolds (/mx10^6)
United Technologies USA	Acoustic	1.5 Dia. l	Mach ≤ 0.65	n.a.	0.16
Georgia Inst. Tech. USA	Low turbulence	1 x 1	3 - 23 m/s	16%/50dB	0.15
NASA Langley R.C. USA	Low turbulence	2.25x0.9x2.25	0.05 - 0.5	n.a.	0.13-5.
Goldstein Research Lab. UK	Low turbulence	0.5 x 0.5 x 3.0	42 m/s	<0.03%/n.a.	n.a.
Maibara RTRI Japan	Low Noise	3 x 2.5 x 8	85 m/s	<0.3%/35dB	n.a.
Audi Germany	Low noise	9 x 15 x 16	83 m/s	n.a./46dB	2
TsAGI Russia	T-32	1 x 1 x 4	2 - 80 m/s	>0.01%/n.a.	0.13-5.3
Royal Institute Sweden	Low turbulence	0.8x1.2x7	68 m/s	<0.02%/29dB	n.a.
SEATTLER Project	Zero driver noise	≤0.4 round	0 - 140 m/s	0.01%/<<10dB	up to 1

The examination of the table allows to point out the clear distinction of the SEATTLER solution, where the driving noise is reduced below 10dB, in contrast to all other high quality facilities, where the best achievement of 29dB is offered in Sweden. It is obvious that the SEATTLER aeroacoustics facility is a high quality tool for the in-depth study of noise emission during aerodynamic flows around profiles, especially through blade cascades of air compressors and turbines. The separation of the soft noise of the flow is usually the main difficulty of all existing installations. A wind tunnel with no moving parts, where the airflow runs under gravity draught only is a crucial advance in this area and this solution is offered by SEATTLER [11].

The high consumption of energy had also found a practical solution with SEATTLER through the involvement of the solar heating. A focusing array of controlled mirrors is used to easy heat the fresh air and produce the draught effect required to accelerate it through the test chamber. When the wind tunnel is not under operation a could air turbine is imagined to be introduced in the airflow, powered by the draught of the air and producing electricity after driving a coupled generator. This dual capability is reducing costs further and offers an unexpected solution for energy.

GRAVITY DRAUGHT FOR AIR ACCELERATION

The source of the gravitational draught is the ascending effect of lower density volumes of warm gases in contrast with the higher density surrounding air as a result of their different weights, quantitatively described by the famous Archimede's law. As far as we keep standing in the frames of this effect of gravity the problem remains entirely immobile. The accompanying buoyant force supplies the maximal estimate for the draught effect. However, when the upward motion of the rarefied gas from the inside is considered, the more elaborated dynamic equilibrium must be approached by the rules of gasdynamics, although its roots remain in the realm of crude Archimede's principle.

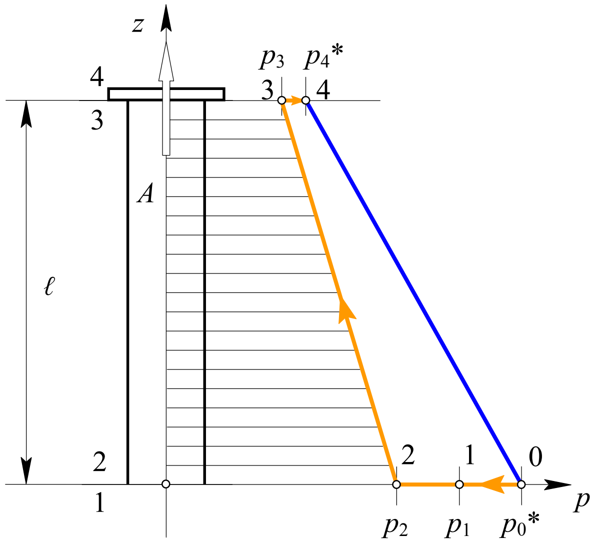


Fig. 4. Dynamics of the gravitation draught.

The draft in Fig. 4 shows a vertical stack circulated by the warmed air that defuses into the atmosphere after exiting its top opening. It is surrounded by higher density cold air and the effect of gravity must be accounted in computing the different inner and outer pressures that act on stack’s walls. For the sake of simplicity, the air density is considered as independent of altitude [11], while different inside and outside.

The aerostatic influence of the gravitation is then given by the gradient equation both inside (density ρ) and (density ρ_0) outside,

$$\frac{\mathrm{d}\,p}{\mathrm{d}\,z} = -g\,\rho\,, \qquad \frac{\mathrm{d}\,p}{\mathrm{d}\,z} = -g\,\rho_0\,. \tag{1}$$

The right hand term in these equations is nothing but the slope to the left of the vertical in each pressure diagram from figure 4, meaning the inner pressure in the stack (left, doted) is decreasing less steeply and remains closer to the vertical than the outer pressure. The dynamic equilibrium is established when, following a series of transforms, the stagnation pressures inside and outside become equal (Fig. 4). While the air outside the stack preserves immobile and due to the effect of gravitation its pressure decreases with altitude from $p_{ou}(0)\equiv p_0$ at the stack's pad to $p_{ou}(\ell)$- at the tip of the stack "4", the inner air is flowing and consequently its pressure p_{in} varies not only by gravitation but also due to acceleration and braking along the 0-1-2-3-4 cycle.

The air acceleration takes place at tower inlet between 0-1 as governed by the energy compressible equation ($\Gamma \equiv \frac{\kappa - 1}{\kappa}$) with constant density ρ_0 along,

$$p_1 = p_0 - \frac{\Gamma}{2} \cdot \frac{\dot{m}^2}{\rho_0 A^2} \,. \tag{2}$$

where A is the cross area of the inner channel and $\dot{m}$ the mass flow rate, constant through the entire stack (steady-state assumption). The air is warmed in the heat exchanger/solar receiver between 1-2 with the heat q per kg with dilatation and acceleration of the airflow, accompanied by the "*dilatation drag*" pressure loss [1]. Considering also A=*const* for the cross-area of the heating zone and adopting the variable γ for the amount of heating rather then the heat quantity itself,

$$\gamma = \frac{\rho_0 - \rho_2}{\rho_0} = 1 - \beta \,, \tag{3}$$

with a given control value for

$$\beta = \frac{\rho_2}{\rho_0} < 1 \,, \tag{4}$$

the continuity condition shows that the variation of the speed is simply given by

$$c_2 = c_1 / \beta \,. \tag{5}$$

The impulse equation gives now the value of the pressure loss due to air dilatation,

$$p_2 + \frac{\dot{m}^2}{\rho_2 A^2} = p_1 + \frac{\dot{m}^2}{\rho_0 A^2} - \Delta p_R \,. \tag{6}$$

where a possible pressure loss Δp_R due to friction into the heat exchanger is considered. Once the dilatation drag is thus perfectly identified, the total pressure loss Δp_Σ from pad's outside up to the exit from the heat exchanger results as depending on the yet unknown mass flow rate $\dot{m}$, as the sum of the inlet acceleration loss (2) and the dilatation loss (6),

$$p_2 = p_0 - \frac{\dot{m}^2}{2\rho_0 A^2} + \frac{\dot{m}^2}{\rho_0 A^2} - \frac{\dot{m}^2}{\rho_2 A^2} - \Delta p_R \equiv p_0 - \Delta p_\Sigma \,, \tag{7}$$

equivalent to

$$p_2 = p_0 - \frac{\dot{m}^2}{\rho_0 A^2} \cdot \frac{\gamma(2 - \Gamma) + \Gamma}{2(1 - \gamma)} - \Delta p_R \,. \tag{8}$$

The gravitational effect (1) continues to decrease the value of the inner pressure up to the exit rim of the stack, where the inner pressure becomes

$$p_3 \equiv p_2 - g\rho_2 \ell = p_0 - \frac{\dot{m}^2}{\rho_0 A^2} \cdot \frac{\gamma(2-\Gamma)+\Gamma}{2(1-\gamma)} - \Delta p_R - g\rho_2 \ell . \tag{9}$$

The constant density assumption along the upper stack $\rho_2 = \rho_3 = \rho_4$ was used. Recovery of the static air pressure, previously [6] considered through a compressible process governed by the Bernoulli equation

$$p_4{}^* = p_3 + \Gamma \frac{\dot{m}^2}{2\rho_2 A^2}$$

is here replaced with the Unger condition [5] of an isobaric exit $p_4{}^* = p_3$ which, considered into (9) for replacing p_3, ends in the equilibrium equation

$$p_4{}^* = p_0 - \frac{\dot{m}^2}{\rho_0 A^2} \cdot \frac{\gamma(2-\Gamma)+\Gamma}{2(1-\gamma)} - \Delta p_R - g\rho_2 \ell . \tag{10}$$

This means that the dynamic equilibrium is re-established when the stagnation pressure from inside the tower equals the one from outside, at the exit level,

$$p_4{}^* \equiv p_{in}(\ell) = p_{ou}(\ell) \equiv p_0(0) - g\rho_0 \ell . \tag{11}$$

This equation is the end element that allows determining the equilibrium value of the air mass flow rate passing through the stack. Equaling (10) and (11),

$$p_0 - g\rho_0 \ell \equiv p_0 - \frac{\dot{m}^2}{\rho_0 A^2} \cdot \frac{\gamma(2-\Gamma)+\Gamma}{2(1-\gamma)} - \Delta p_R - g\rho_2 \ell . \tag{12}$$

Reducing by the quotient $g\rho_0\ell$ the equilibrium equation appears in the form

$$\frac{\Delta p(\ell)}{g\rho_0 \ell} \equiv \frac{1+\gamma-\Gamma}{1-\gamma} \cdot \frac{\dot{m}^2}{2g\ell\rho_0{}^2 A^2} + \frac{\Delta p_R(\ell)}{g\rho_0 \ell} - \gamma = 0 . \tag{13}$$

Depending on the construction of the heat exchanger the drag largely varies. For simple, tubular channels the pressure loss due to frictions stands negligible [6], [8], [9] and the reduced mass flow rate (RMF) results from the simple equation

$$R^2 \equiv \frac{\dot{m}^2}{2g\ell\rho_0{}^2 A^2} = \frac{\gamma \cdot (1-\gamma)}{\gamma(2-\Gamma)+\Gamma} . \tag{14}$$

It represents an alternative to the previous solution of Unger in 1988 [5]

$$R^2 = \frac{\gamma(1-\gamma)}{1+\gamma} \tag{15}$$

or to the one of Rugescu [6]

$$R^2 = \frac{\gamma(1-\gamma)}{1+\gamma-\Gamma} \tag{16}$$

and gives optimistic values in the region of smaller values of heating (Fig. 5).

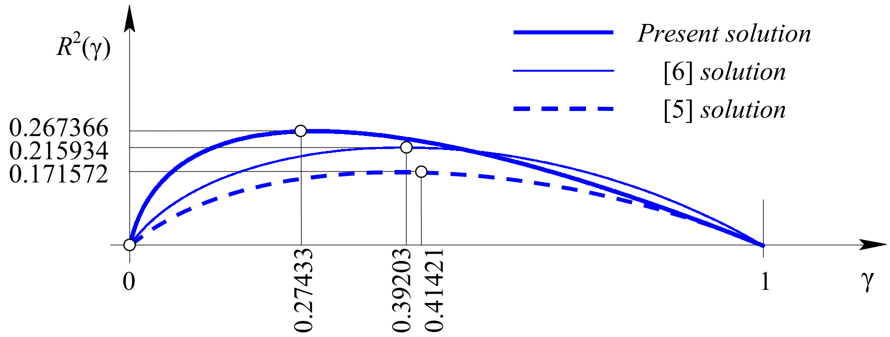


Fig. 5. Stack discharge R^2 versus air heating intensity γ.

The accelerating potential and the expense of heat to perform this acceleration at optimal conditions result from equations (14)-(16). In a practical manner, the velocity c_2 results in regard to the free-fall velocity (Torricelli) c_ℓ. Its upper margin is given by (17) through (14) while the lower margin by (18) through (15),

$$c_{2H} = \sqrt{\frac{\gamma \cdot 2g\ell}{(1-\gamma)[\gamma(2-\Gamma)+\Gamma]}}, \quad (17) \qquad\qquad c_{2L} = \sqrt{\frac{\gamma \cdot 2g\ell}{1-\gamma^2}} \quad (18)$$

In fact these formulae render identical results for the optimal g values (Table 2). For a contraction aria ratio of 10 the maximal airflow velocities in the test chamber c_e of the aeroacoustic tunnel versus the tower height are given in Table 2.

Table 2. Draught vs. tower height for a contraction ratio 10.

ℓ *m*	c_ℓ *m/s*	c_1 *m/s*	c_2 *m/s*	c_e *m/s*
7	11.72	4.85	8.28	82.8
14	16.57	6.86	11.72	117.2
30	24.26	10.05	17.15	171.5
70	37.05	15.35	26.20	262.0
140	52.40	21.71	37.05	370.5

The value of c_e was computed according to the simple, incompressible assumption, which renders a minimal estimate for the air velocity in the contracted area. Compressibility whatsoever will tend to increase the actual velocity in the test area, while drag losses, especially in the heat exchanger, will decrease that speed.

ORGANISATION OF THE RESEARCH AREA

The height of the construction is from 20-*m* to 140-*m*. Below and around the test chamber situated at floor 1 a multi-purpose building of the laboratory will be installed (Fig. 6,a). The air inlets are located above the ground floor (Fig. 6,b).

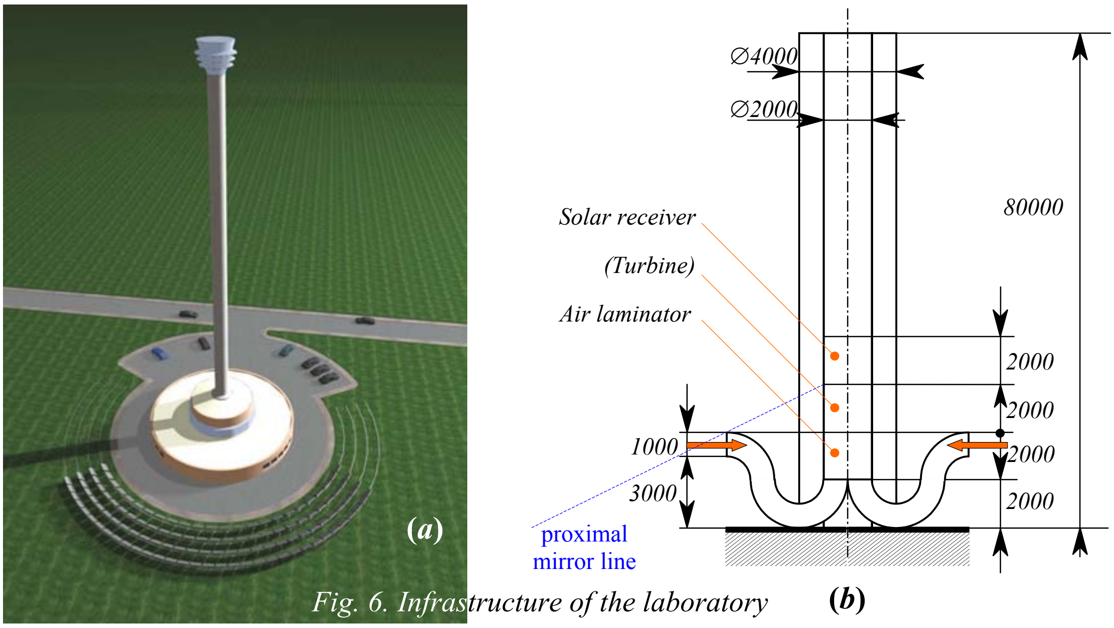


Fig. 6. Infrastructure of the laboratory

A surface of around 0.8 *ha* suffices [7] to collect enough solar energy for powering the aeroacoustic wind tunnel at its maximal capacity.

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