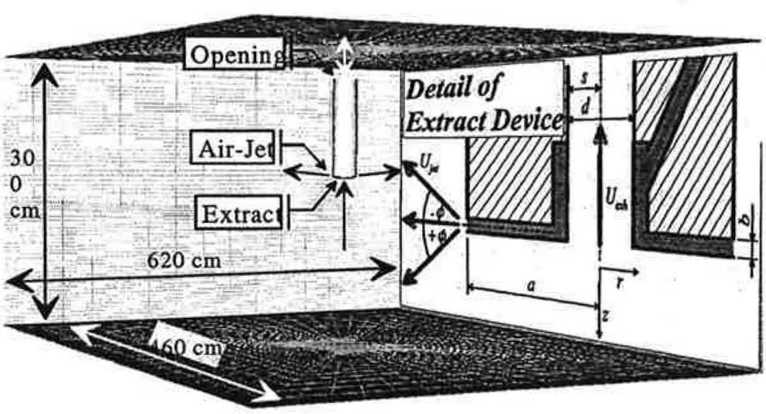
Tuning of a Reinforced Extract System by Computational Fluid Dynamics

Gubler D, Moser A
Institute für Hochbautechnik, Zürich, Switzerland

Introduction

Due to poor air quality at the working place, illness of the respiratory tract may arise. Capture of contaminated air near its source is one of the most effective ways to protect workers' health. Local ventilation systems are used in many industries but the suction range of traditional systems is very limited as they draw air from all directions even from behind the exhaust. The basic concept of an exhaust with enhanced suction range that captures airborne contaminants at their origin without obstructing the work area was presented for the first time in 1965. That early device was called Aaberg Ventilator (1). The basic idea is to use a secondary jet to entrain and thereby attract a large volume of ambient air to the suction opening of the extract system. Shrouded in this general streamline pattern, the contaminated air is guided to the extract. Different experimental and theoretical studies have demonstrated the performance of the system ((2, 3), and (4)). Nevertheless, it is not applied to industrial ventilation at this time.

The objective of the ongoing project is the development of an optimized design for an enhanced capture extract system. The study should provide knowledge about the influence of design parameters on the performance of the system and about the sensitivity of capture distance to parameter variation. This paper describes the influence of the jet angle *F* on the behavior of the system. Computational Fluid Dynamics (CFD) are used as a design tool along with measurements on prototypes. The reliability of CFD-calculations was checked and the numerical method validated by comparison with experimental data (6). Figure 1 shows the setup for the CFD calculations and explains the basic operation and nomenclature.



F Jet-Angle (0°= normal to system axis)
AF Amplification Factor $U_{with\,jet}/U_{without\,jet}$
CD Capture Distance
I Momentum flux ratio between exhaust and jet
Uexh Average exhaust face velocity
Ujet Average jet nozzle velocity
Qexh Volumetric exhaust flow rate
Qjet Volumetric jet flow rate
a Radius of the exhaust flange
b Width of the jet nozzle
d Diameter of the exhaust, $d=2s$
r Radial-coordinate
s Radius of the exhaust
u(z) Center-line air velocity at positi
z Axial-coordinate

Figure 1. Overview of experimental and CFD setup including principle schematic projected on an inside wall and nomenclature

The CFD Model

The current study is based on calculations using a commercial code with multi-grid-capability (5). Turbulence is modeled by the standard k-ε-model. The CFD calculations were validated by comparison with experimental data. Therefore an experimental setup was built and detailed measurements of the velocity field in front of an exhaust were carried out. These results and a detailed validation of the CFD-model are discussed in (6). The exhaust device is mounted vertically in the center of the room with the exhaust face 1.7m above the floor. To balance the difference between the volumetric flow rates of supply jet and exhaust, a third opening is defined, where air exchange to the outside of the chamber is possible. The set of operating parameters for this study corresponds to the measurements. It is defined by the ratio of momentum flow of supply jet and exhaust $I=Q_{jet}U_{jet}/\{Q_{exh}U_{exh}\}$. The ratio is set to be $I=0.82$ with an extracted volume flow rate of $Q_{exh}=465m^3/h$ $(U_{exh}=15.5m/s)$ and a supplied flow rate of $Q_{jet}=300m^3/h$ $(U_{jet}=19.65m/s)$.

Influence of the Jet Angle on the Suction Range

To optimize the design and the operation of a jet-enhanced extract system, it is most important to isolate single design parameters to find out what influence each one has on the global system. In the following, the main influence of a variation of the jet angle F is presented. The angle is assumed to be 0° if the jet blows normal to the exhaust axis. CFD-calculations were done for different angles, otherwise using exactly the same boundary conditions. The angles ranged from -15° (backwards) to +20° (forward). Figure 2 shows streamlines for some jet angles. Weightless particles released from the jet nozzle follow the radial air jet, with increasing jet angle, the jet sheet bends towards the exhaust face. Also illustrated are - backwards integrated - streamlines towards the exhaust face.

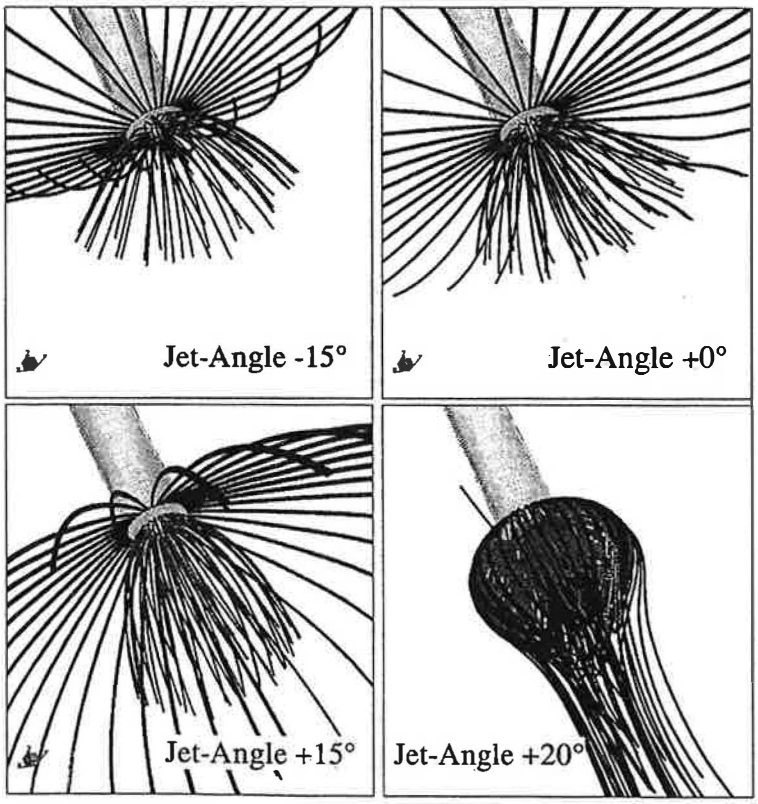


Figure 2. Streamlines of weight-less particles leaving (dark) the jet nozzle and moving towards the exhaust for different angles

For angles between -15° and +10° only small differences in the velocity field were detected. At higher angles, the particle traces of the jet air bend towards the capture zone and, if the angle is too large, the system collapses into a short circuit. A critical angle of +20° was observed. The effect of a forward directed supply jet is a "virtual enclosure" of the capture zone. Inside this zone higher

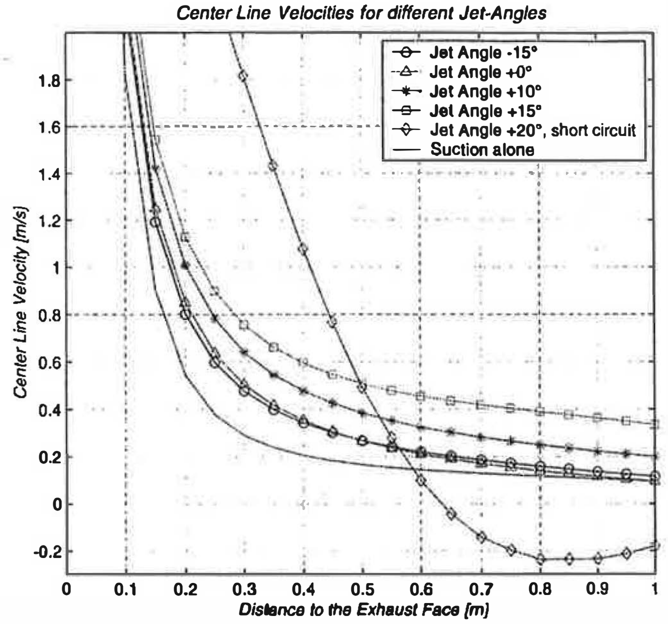


Figure 3. Center line velocities for different angles, including the velocity line for suction alone

velocities are encountered. Figure 3 show the centerline velocities as a function of the distance to the exhaust for the corresponding angles of figure 2. To give an idea of the difference between the enhanced system and a conventional system, the velocity line of a conventional exhaust hood is illustrated too.

The highest velocities (without short circuit) are found for a jet angle slightly below the critical angle of +20°. For angles above the critical value, the velocities are very high for zones close to the exhaust but are decreasing rapidly with increasing distance. To determine an optimized angle *F*, the amplification factor $AF(z)=U_{with\,jet}(z)/U_{without\,jet}(z)$ as a function of the center-line distance was calculated for different angles (Figure 4). The amplification reaches a maximum between a distance of z=0.3 and 0.5 to the exhaust face, this corresponds to a desired suction range for local ventilation systems.

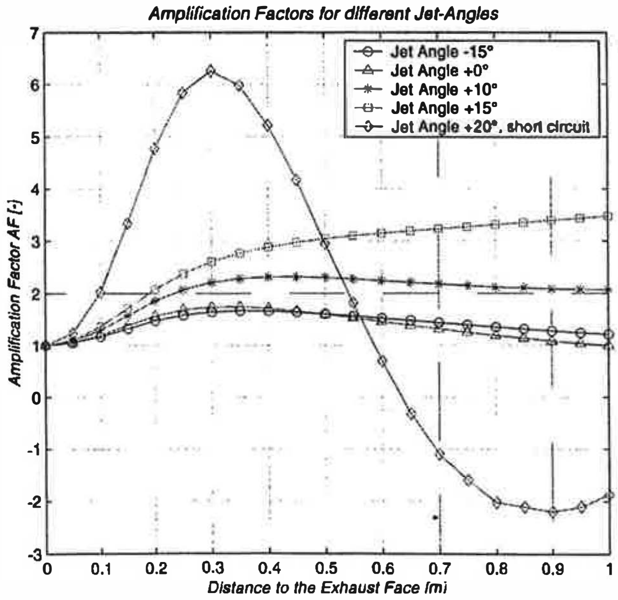


Figure 4. Amplification Factor $AF = U_{with\,jet} / U_{wihout\,jet}$ *for different jet angles*

For practical applications, another parameter, the suction range or capture distance, is of primary interest. The capture distance CD is defined as the distance from the exhaust face where air velocities larger or equal to a minimum critical air velocity directed towards the exhaust prevail (for welding, the minimum required velocity is between 0.5-1.0m/s). The capture distance grows significantly with increasing angle *F*, as long as the system does not collapse.

Figure 5 shows the capture distance as a function of the jet angle *CD=f(F)*. The function has its maximum at approximately *+18°* depending on the desired minimum velocity.

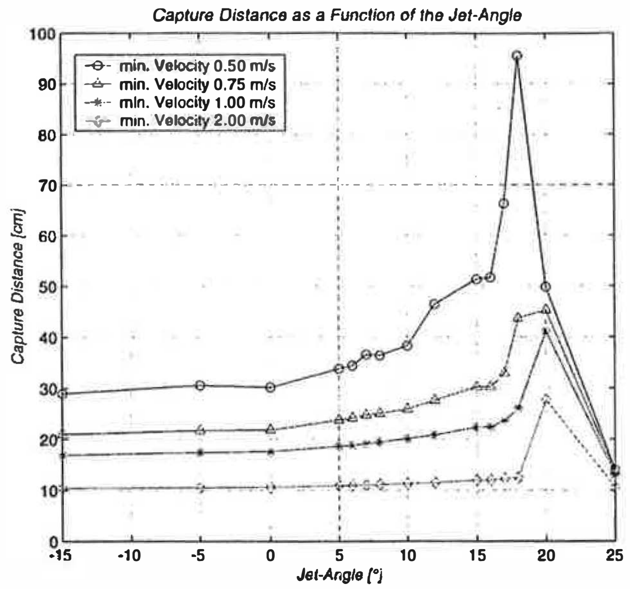


Figure 5. Capture Distance CD as function of jet angle. CD's for suction alone are 22cm for U_{min}=0.5m/s, 17cm: U_{min}=0.75m/s, 14cm: U_{min}=1.0m/s, 10cm, U_{min}=2.0m/s

Conclusions

CFD is a useful design tool for optimization tasks. After setting up and verifying a particular CFD-model, variations of single parameters are done very easily. This study shows potentials for further optimization of the known principle for enhanced extraction. Design parameters like the jet angle have a significant effect on the behavior and the performance of the system. A critical factor for the design is the transition, where the forward bending air jet turns into a short circuit. Thus, two strategies are possible to get a good performance:

1. Enclose the source of contaminant by the local region of short circuit and thus avoid particles to reach the worker's breathing zone
2. Avoid short circuit but optimize the suction range of the system with a slightly forward bending air jet.

Using the whole potential for optimization, the jet-enhanced system is a very powerful system for local ventilation, and industrial applicability is a realistic target.

The influence of side effects like cross drafts and movements of workers in the operating zone have to be determined. Also the stability of the system must be investigated using CFD or experimental setups.

References

1. Aaberg, C.P.: Specific Flow Distribution, 1970 (in Danish).
2. Pedersen L. G. and Nielsen P. V., (1991) Exhaust System Reinforced by Jet Flow, *ROOMVENT'91. Int. Conf. On Air Distribution in Ventilated Spaces,* Cincinnati.
3. Saunders, C.J., Fletcher, B.: (1993) Jet Enhanced Local Exhaust Ventilation, *Ann. Occup. Hyg.,* Vol.37, Nr.1.
4. Hunt, G.R. and Ingham, D.B.: (1993) A Three-dimensional Axisymmetric Model of the Air Flow Pattern Created by a Local Exhaust Ventilation System Reinforced by a Turbulent Radial Jet Flow, *J. Aerosol Science,24, Suppl 1, 15–16.*
5. "TASCflow User documentation", Advanced Scientific Computing Ltd., October 1995.
6. Gubler, D. and Moser, A.: (2000) Reinforced Extraction System: Evaluation of Optimized Operating Parameters using CFD, *ROOMVENT 2000. Int. Conf. On Air Distribution in Ventilated Spaces,* Reading.