#4939

# Two-dimensional Non-Isothermal Supply from Low Velocity Terminals

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## Introduction

The distribution of air within a room with traditional mechanical ventilation is based on a principle which entails the supply of air with a high initial velocity, usually several meters per second. These high velocity terminals are used in connection with *mixing ventilation*. Isothermal flow issuing from this type of terminal is governed by the initial momentum flux and is therefore of the jet type.

High velocity air terminals are used for the supply of both isothermal air and non-isothermal air. In the latter case the flow is affected by both momentum (inertia) and buoyancy forces created by the density differences. The ratio between buoyancy and momentum is often expressed by the Archimedes number (see below). When non-isothermal air is supplied with a high velocity air terminal the inlet Archimedes number is very small, typically less than $10^{-2}$. This reflects the fact that, due to a high velocity, the momentum is initially stronger than the buoyancy force.

During the last decade air terminals designed for the supply of air with low velocities, typically around 0.2 meters per second, have been introduced. Low velocity air terminals are frequently used as a component in so called *ventilation by displacement*. In this application the terminals are usually located at floor level and air at a lower temperature (negatively buoyant) is supplied and intrudes into the room as a horizontal current, see Fig. 1. Due to the low inlet velocity the buoyancy now becomes relatively more important than with supply by a high velocity air terminal. The nominal Archimedes number based on inlet conditions is large and is often greater than one. Due to the stabilizing effect of the buoyancy, the entrainment of ambient air is hindered. Therefore the kind of flow issuing from this type of terminal is no longer of the jet type. The discharge is more like *gravity currents*.

In the field of ventilation engineering the understanding of jet types of flow is well established. However, the behaviour of buoyant flows with high initial Archimedes numbers has been much less explored. The aim of this short note is to highlight some of the differences between ordinary jet flow and the discharge from low velocity air terminals. Results are presented both from tests carried out in a full scale mock up and from model tests with water as operating fluid. For design purposes, knowledge about the maximum velocity is important in order to avoid complaints about the thermal sensation. Consequently in this note we concentrate on the maximum velocity generated by this type of flow.

## Inlet Conditions

We will assume that we have a two-dimensional flow so that the flow fills up the whole width of the room and therefore all quantities are given per unit width. Two-dimensional flow may occur either when the inlet terminal span the whole width of the room or when the radial flow from a narrow terminal reaches the side walls.

At the inlet we have the following variables.

| | | |
|---|---|---|
| Volumetric flow rate: | $q$ | $[\frac{m^2}{s}]$ |
| Density difference: | $\Delta\rho$ | $[\frac{kg}{m^3}]$ |
| Height of the terminal: | $H$ | $[m]$ |
| Inlet (supply velocity): | $U_s$ | $[\frac{m}{s}]$ |

It is convenient to express the effect of the density difference as the *reduced gravity:*

$$g' = \frac{\Delta\rho}{\rho_s} g \qquad [\frac{m}{s^2}]$$

From the above variables we derive:

*Specific momentum flux*: $[\frac{M}{\rho_s} = q.U_s]$ $\qquad [\frac{m^3}{s^2}]$

*Specific buoyancy flux:* $B = qg'$ $\qquad [\frac{m^3}{s^3}]$

The specific momentum flux and the height give the velocity scale based on momentum

$$\sqrt{(\frac{M}{\rho H})} = U_s \qquad [\frac{m}{s}]$$

From the dimensions of the specific buoyancy we see that a velocity scale based on buoyancy can be derived, which is equal to:

$$B^{1/3} \qquad [\frac{m}{s}]$$

Whether the air will be driven by gravity (buoyancy) or the initial momentum of the discharging air depends on the magnitude of the *initial Archimedes number,* Ar:

$$Ar = \frac{g'H}{U_s^2} \qquad [1]$$

An isothermal jet (g' = 0) has an Archimedes number equal to 0. The flow is said to be *subcritical* if the Archimedes number is greater than one and *supercritical* if the Archimedes number is less than one. Jump-like transitions may occur if the inlet Archimedes number is less than one.

## Measurements

By studying a starting flow situation (the flow is turned on), insight will be gained into the physics involved. Studies of starting flows were carried out in a model with water as operating fluid. Salt was added to the supply water to obtain the desired density difference. Fig. 1 shows a shadowgraph of a starting flow.

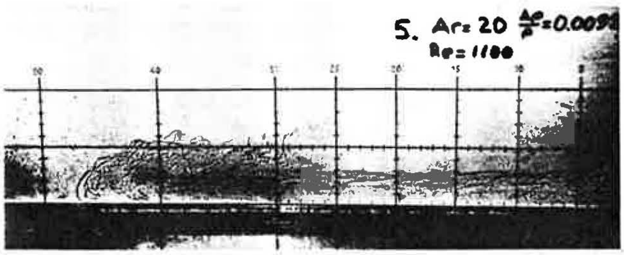

*Figure 1 Shadowgraph of the head of the starting flow advancing towards the left*

Because we have a two-dimensional flow we should expect the velocity to approach a constant value, after an initial acceleration phase at the inlet. The recorded velocities of the front, $U_f$, are summarized in Fig. 2

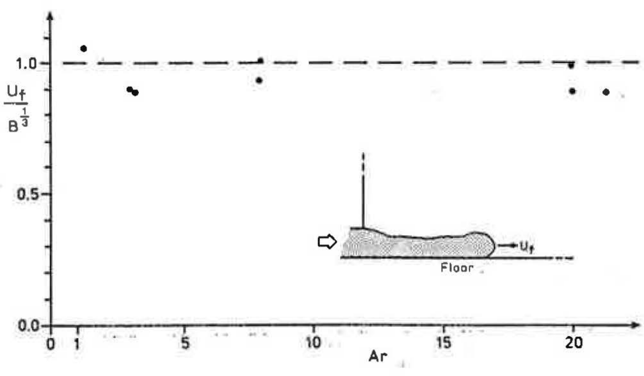


*Figure 2 Starting flow. Velocity of the front, $U_f$*

We see that the velocity of the front becomes close to the buoyant velocity scale, $B^{1/3}$. This is typical for two-dimensional gravity currents, see e.g. Simpson J E (1987). Simpson's book also gives other relevant references on gravity currents.

The next figure shows the vertical velocity profiles recorded 1.5 m from the supply terminal in a mock up of an office room. The height of the terminal amounted to 0.485 m. Only stationary situations were studied in the mock up.

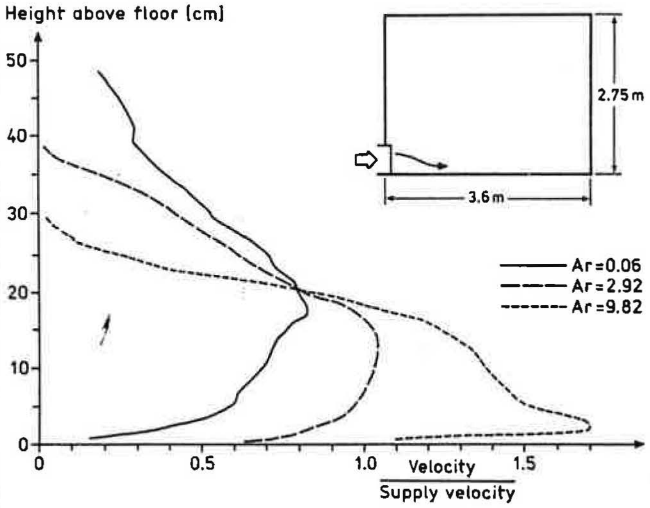


*Figure 3 Stationary flow. Velocity profiles recorded 1.5 m from the terminal*

We see that the shape of the velocity profile is dependent on the Archimedes number. At the lowest Archimedes numbers the maximum velocity is less than the supply velocity. This is typical for a jet which entrains ambient air so that the velocity is reduced. The buoyancy initially accelerates the flow such that at large Archimedes numbers it becomes greater than the supply velocity. Fig. 4 shows a plot similar to that of Fig. 2 for the recorded maximum velocity. For an inlet Archimedes number equal to or greater than one the maximum velocity has been divided by the velocity scale given by the buoyancy (filled circles), whereas for an Archimedes number less than one it has been divided by the velocity scale introduced by the specific momentum flux (open circles).

We see that for an Archimedes number equal to and greater than one the maximum velocity is given by the buoyant velocity scale. The scatter is now larger than in Fig. 2. This can be attributed to the facts that the experimental difficulties are now greater than in the previous case and that the specific buoyancy flux is no longer conserved. This is due to the circumstance that there is a heat transfer between the floor and the air layer above it that will gradually diminish the initial buoyancy flux. Furthermore in Fig.4 we have assumed that the velocity profile is uniform. However, this far from the case as we see in Fig.2 and therefore an Archimedes number dependent correction factor should have been introduced, which has not been done.

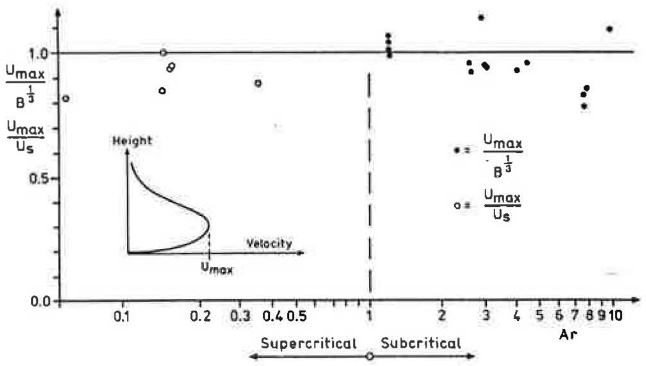


*Figure 4 Stationary flow. Maximum velocity*

For an Archimedes number less than one the buoyant velocity scale is not the appropriate one. Instead the velocity scale based on the supply velocity, that is to say the momentum induced velocity scale is the correct velocity scale. We see that the maximum velocity is now always less than the inlet velocity. This is because entrainment of ambient air slows down the velocity. Another contrast between the jet type of flow and this type of flow is the influence of the downstream conditions. An ordinary jet supplied at floor level that arrives at a wall is deflected and continues to flow along the wall, whereas a gravity current may be reflected back. Therefore a starting gravity current may in the limit become submerged into its "own" air. However, if the wall is heated then a fraction of the original flow will continue along the wall. There are several other possible types of downstream controls. In the tests reported here the two-dimensional current was allowed to flow out into a wider room far downstream and therefore there was no immediate reentrainment of the supplied air.

## Conclusions

For two-dimensional flow it has been shown that when the Archimedes number based on inlet conditions is equal to or greater than one then the flow is no longer of the jet type. The flow is governed by buoyancy and the maximum velocity becomes nearly equal to the specific buoyancy raised to one third, which is the *buoyancy induced velocity scale.* Therefore the buoyancy flux is the decisive factor that governs the velocity when buoyancy is the dominating force. The Archimedes number is a parameter for identifying different flow regimes. An additional contrast between this type of flow and jet type flow is that the downstream conditions may affect the flow.

## References


Sandberg M & Holmberg S (1990) "Spread of supply air from low velocity air terminals." Proceedings ROOMVENT'90. Oslo, Norway, June 13-15

Simpson J E (1987) GRAVITY CURRENTS. Ellis Horward Limited


Mats Sandberg & Magnus Mattsson, National Swedish Institute for Building Research "Two-dimensional non-isothermal supply from low velocity terminals"

# New member of staff at AIVC - John Kendrick

John joined the group in the new year. He has a first degree in Mechanical Engineering from Leicester University and is currently completing his PhD. in aerodynamics, also at Leicester. He has worked on computer and wind tunnel modelling of aircraft drag factors for the development of the British Aerospace A330/A340 Airbus.

He has been involved in extensive wind tunnel testing in Leicester as well as working at British Aerospace in the aerodynamics design office. Experience in flow modelling and an engineering background will be useful for the project he is currently working on at the Air Infiltration and Ventilation Centre.

John is initially involved in the assessment of "state of the art" theoretical models for the combination of fluid flow and heat transfer, with particular attention to model comparison with real life measurement problems and solutions.