The author presented an original approach of the problem of self-aeration in spillway chute. He should be congratulated for his challenging development. The work is helpful in gaining a better understanding of the spillway chute aeration. The discusser wishes to add further information for completeness. Important references are missing and large-scale data were omitted.

Some bibliography
Self-aeration down open chutes has been investigated for nearly a century. The discusser retraced recently the historical development (CHANSON 1997a, pp. 104-106 & 110-111). He highlighted in particular the significant contributions of three researchers and their teams: R. EHRENBERGER in Austria, L.G. STRAUB in USA, and I.R. WOOD in New Zealand. The bibliography on self-aerated flows is broader than suggested by the author. For example some important progresses were made in the 1980s: e.g., KOBUS (1984) and WOOD (1985). Recently comprehensive reviews include the books of WOOD (1991) and CHANSON (1997a).

Self-aerated flow structure
Several large scale experiments were performed with self-aerated chute flows (table 1). The experimental results provide information which were not taken into account by the author and which are discussed below.

Downstream of the critical point (or inception point of air entrainment), a dominant feature of high-velocity chute flow is the homogeneous nature of the air-water mixture. Between 0 and 90% of air content, the air-water flow properties (void fraction, mean velocity, air bubble frequency) exhibit smooth variations with distance from the invert (e.g. CHANSON 1997b). There is no discontinuity between a "drops" region and a "bubbles" region, and the author's figure 1 could be misleading.

The discusser's experience with air-water flows suggests that self-aerated chute flows consist of a bubbly flow region for low air contents and a highly-aerated flow mixture for C > 0.3 to 0.4 (fig. 1, CHANSON 1997a). At large air contents, the air-water mixture consists of air-water projections and foam. Both air-water projections and foam structures are instantaneous structures which constantly evolve in shapes and sizes.

Indeed the concept of "free-surface" is arbitrary in self-aerated chute flows. In clear-water flow, the air-water interface is well-marked and the free-surface may be accurately measured with a pointer gauge. In self-aerated flow, the exact location of the interface between the flowing fluid and the above atmosphere becomes undetermined. Several researchers proposed various criterion. CHANSON (1997a) defined the interface between the air-water mixture flow and the atmosphere as the iso-air concentration line C = 90%. The choice of 90% air content as the 'free-surface' can be

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justified because it satisfies the continuity equation for water as demonstrated by CAIN (1978) and CHANSON (1988). That is:

\[
\frac{Q}{W} = \int_0^{y_C=0.9} (1 - C) \cdot V \cdot dy
\]

where \( Q \) is known, and the air content and velocity are measured between \( y = 0 \) (invert) and the distance \( y \) normal to invert where \( C = 0.9 \).

**Experimental data: maximum drop height**

The discusser would like to add new information on maximum drop height observations. Recent experiments were performed in a large flume (CHANSON 1997b, table 1). The characteristic flow velocity and flow depth were about 3.4 to 5.4 m/s and 30 to 44 mm respectively. Droplet ejection heights were commonly observed to exceed 0.4 m (i.e. sidewall height).

Drop height observations were made also in stepped cascade flows. CHANSON and TOOMBES (1997) observed maximum drop heights in excess of 0.6 m for the following flow conditions: \( h \sim 0.03 \) m, \( U \sim 1.5 \) to 3 m/s, step height = 0.14 m, longitudinal slope = 3.4 degrees. More generally droplet ejections and spray are common features of cascading waters.

**Experimental data: distributions of drop chord length**

A detailed study of the air-water flow structure in a large flume was performed by the writer (CHANSON 1997b). The data analysis includes distributions of air bubble chord lengths and of water drop chord lengths. Bubble chord length data were presented elsewhere (CHANSON 1997a,b).

Examples of drop chord length distribution are shown in figure 2. The data were recorded at various locations \( \{x,y\} \) and the local air-water flow properties \( (C, V) \) are indicated in caption as well as the number of recorded drops during the scanning period. The histogram columns represent each the number of drops with chord length in a 0.5-mm interval: e.g., the number of drop with chord length between 2 and 2.5 mm is represented by the column labelled 2.5-mm.

The results (fig. 2) indicate a broad spectrum of water drop chord lengths. The range of chord length extends over several orders of magnitude: e.g., from 0.5 mm to 82 mm in figure 2A and between 0.3 mm to over 40 mm in figure 2B. Although the distributions appeared skewed with a preponderance of small drop sizes relative to the mean in figure 2A, the distributions are almost flat at very large air content (i.e. \( C \geq 0.9 \)) as illustrated in figure 2B. For comparison, the author's equation (7) would predict a minimum radius of water droplets of more than 25 mm. Such calculations are not accurate as indeed pointed by the author himself.

**Summary and recommendations**

The discusser would recommend to extend the author's analysis to large scale and prototype data: e.g., the works of CAIN (1978) and CHANSON (1997b) (table 1).

It was shown that the distributions of air bubble chord sizes exhibit a broad spectrum and that the range of bubble chord length extends over several orders of magnitude (CHANSON 1997b). Similarly a re-analysis of the discusser's data

(fig. 2) suggests a broad range of water drop sizes. A study of both drop sizes and bubble sizes is required to gain a better understanding of the air-water flow mixture and it would have direct applications in terms of water quality and air-water gas transfer at and downstream of hydraulic structures.

REFERENCES


NOTATION

\[ C = \text{local air concentration; } \]
\[ Q = \text{water discharge (m}^3\text{/s); } \]
\[ V = \text{local velocity (m/s); } \]
\[ W = \text{channel width (m); } \]
\[ y = \text{distance (m) measured normal to the invert.} \]
Table 1 - Large-scale experiments in self-aerated chute flows

<table>
<thead>
<tr>
<th>Reference</th>
<th>Slope</th>
<th>U m/s</th>
<th>h m</th>
<th>U*h/v</th>
<th>Location</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROTOTYPES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAIN (1978)</td>
<td>45.0</td>
<td>15.6</td>
<td>0.126 to 18.5</td>
<td>0.191</td>
<td>2.2E+6 to 3.2E+6</td>
<td>Aviemore dam, New Zealand</td>
</tr>
<tr>
<td>LARGE MODELS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHANSON (1988)</td>
<td>52.3</td>
<td>8.8 to 12.4</td>
<td>0.021 to 0.034</td>
<td>2E+5 to 5E+5</td>
<td>Clyde model, New Zealand</td>
<td>Perspex flume. W = 0.25 m.</td>
</tr>
<tr>
<td>ARREGUIN and ECHAVEZ (1986)</td>
<td>0</td>
<td>14.9 to 24.1</td>
<td>0.14 to 0.23</td>
<td>1.3E+6</td>
<td>Mexico Lab., Mexico</td>
<td></td>
</tr>
<tr>
<td>XI (1988)</td>
<td>52.5</td>
<td>8.3 to 11.1</td>
<td>0.029 to 0.038</td>
<td>3E+5</td>
<td>Meishan Hydraulic Lab., China</td>
<td>Timber. W = 0.6 m.</td>
</tr>
<tr>
<td>CHANSON (1997b)</td>
<td>4.0</td>
<td>3.4 to 5.5</td>
<td>0.030 to 0.044</td>
<td>1.3E+5 to 1.45E+5</td>
<td>Univ. of Queensland, Australia</td>
<td>Painted timber. W = 0.5 m.</td>
</tr>
</tbody>
</table>

Note: W: channel width.

Fig. 1 - Air-water flow structures in self-aerated chute flows
Fig. 2 - Drop chord length distributions (0.5-mm drop chord length intervals)

(A) Flow conditions: \( x = 12 \text{ m}, U = 3.56 \text{ m/s}, y = 0.045 \text{ m}, C = 0.81, V = 4.24 \text{ m/s} \) - Scanning rate: 40 kHz, duration: 1.638 s, 87 water drops

\[ x = 12 \text{ m}, C = 0.81, y = 0.045 \text{ m} \]
Fig. 2 - Drop chord length distributions (0.5-mm drop chord length intervals)
(B) Flow conditions: $x = 23$ m, $U = 3.41$ m/s, $y = 0.048$ m, $C = 0.90$, $V = 3.76$ m/s - Scanning rate: 40 kHz, duration: 1.638 s, 46 water drops

$x = 23$ m, $C = 0.90$, $y = 0.048$ m