Session A4- New turbulence parameter for fish passage habitat

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New turbulence parameter for fish passage/habitat

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Reverse Flow Tubes for fish passage - turbulence parameters didn’t adequately describe flow.
British physicist Sir Horace Lamb once said: "I am an old man now, and when I die and go to heaven there are two matters on which I hope for enlightenment. One is quantum electrodynamics, and the other is the turbulent motion of fluids. And about the former I am rather optimistic."

In fluid flow, turbulence is simply defined as random velocity fluctuations.
Additionally, the following parameters can be used to further describe turbulence.

- Three-dimensional vortices
- Random orientation in space
- Rotational
- Stochastic (described by statistical terms)
- Diffusive (a marked particle wanders away from the average direction of flow and on average doesn’t return)
Turbulence is often quantified by:

- Size of the vortices (characteristic length or turbulence scale/length)
- Vorticity (rotational velocity), \( \omega \)
  \[ \omega = \nabla \times \text{velocity} = \text{curl of velocity} \]
- Strength: vorticity \( \times \) cross-sectional area of flow
Turbulence Cascade

Big whirls have little whirls
which feed on their viscosity;
and little whirls have lesser whirls,
and so on to viscosity.

(Poem by Lewis F. Richardson)
Classification of Turbulence

- CFD
- Turbulence Structure
- Shearing Turbulence
- Response Turbulence

Random patterns with creation and destruction of vortices
Classification of Turbulence

Characteristics

- Small scale relative to overall flow field (at sub-grid level)
- RANS and Turbulence Closure
- Defined time step (dt)
Classification of Turbulence

Characteristics

- High strength
- Controls movement of fish
- May damage fish

Shearing Turbulence

Response Turbulence

Rate of strain of a fluid element due to effects of viscosity

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Classification of Turbulence

Characteristics

- Large and small vortices that elicits a response from fish (pressure and acceleration/deceleration)
- Detected through lateral lines/inner ear.
- May evoke avoidance or attraction response
Energy Dissipation Factor (EDF)

Generally applied to a fishways with a given head drop between pools.

\[ EDF = \frac{\gamma Q \Delta h}{V} \]

Where

- \( \gamma \): specific weight
- \( Q \): flow rate
- \( \Delta h \): head drop
- \( V \): volume of pool
Root Mean Square (RMS)

Given a set of $n$-values, $\text{RMS} = \text{square of the mean sum of the squares}$

Usually applied to velocity fluctuations (perturbations), $v'$

$$\text{RMS} [v'_i] = \sqrt{\left( \frac{1}{n} \sum_{i=1}^{n} v'_i^2 \right)}$$

$$= \sqrt{\frac{1}{n} \sum_{i=1}^{n} (v' - v_i)^2}$$

$$= \sqrt{\frac{1}{n} \left( n \sum_{i=1}^{n} v_i^2 - \left( \sum_{i=1}^{n} v_i \right)^2 \right)}$$
Turbulence Intensity

\[ T_i = \frac{RMS[v_i]}{U_{ref}} \times 100 \quad \text{where } U_{ref} \text{ is a reference velocity} \]

Note: if \( k \) (kinetic energy per unit mass) is given as:

\[ k = \frac{1}{2} \left( \overline{u'^2} + \overline{v'^2} + \overline{w'^2} \right) \]

then

\[ T_i = \frac{\left( \frac{2}{3} \times k \right)^{\frac{1}{2}}}{U_{ref}} \times 100 \]
RMS/Turbulence Intensity Limitations

Given velocity samples:

<table>
<thead>
<tr>
<th>Sample Velocities</th>
<th>Smooth</th>
<th>Pulsing 1</th>
<th>Pulsing 2</th>
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<td>Kurtosis</td>
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</tbody>
</table>
Turbulence Parameter

Goal: define a measurement that more accurately indicates conditions in the flow field

- Easy to measure in the field
- Evaluates turbulence from a fishes perspective
- Contained within the “response turbulence” region
- Captures much of the three-dimensionality, rotational, random and diffusive pattern of turbulence
Three-axis Method

Change in velocity = acceleration/deceleration

Given a velocity vector, \( \vec{V} = V(x, y, z, t) \)

Full derivative

\[
\frac{D\vec{V}}{Dt} = \frac{\partial \vec{V}}{\partial t} \frac{dt}{dt} + \frac{\partial \vec{V}}{\partial x} \frac{dx}{dt} + \frac{\partial \vec{V}}{\partial y} \frac{dy}{dt} + \frac{\partial \vec{V}}{\partial z} \frac{dz}{dt}
\]

\[
= \frac{\partial \vec{V}}{\partial t} + u \frac{\partial \vec{V}}{\partial x} + v \frac{\partial \vec{V}}{\partial y} + w \frac{\partial \vec{V}}{\partial z}
\]

local derivative \hspace{1cm} material derivative
Three-axis Method

Defines region of acceptable turbulence

Incorporates:

- Local accelerations/decelerations
- Strengthen based on average resultant velocity
- Rotation based on change in angle

\[ \theta_{1-2} = a \cos \left( \frac{\vec{V}_1 \cdot \vec{V}_2}{||\vec{V}_1|| \cdot ||\vec{V}_2||} \right) \]
Average Vector Method

Simplify:

- **Strength:** Average velocity resultant magnitude
  \[
  V_{\text{ave}} = \frac{(V_1 + V_2)}{2}
  \]

- **Acceleration:**
  \[
  a = \frac{(V_2 - V_1)}{dt}
  \text{ also }\ V_{\text{ave}} = V_1 + \left(\frac{1}{2}a\right)dt
  \]
  substitution gives
  \[
  V_{\text{ave}} = \frac{(V_1 + V_2)}{2}
  \]

- **Rotation:**
  \[
  \frac{d\theta}{dt}
  \]
Average Vector Method ($T_f$)

Combine:

- $$T_f = \left( \frac{V_1 + V_2}{2} \right) \frac{d\theta}{dt} = V_{ave} \frac{d\theta}{dt}$$

- Statistics: mean, standard deviation, skew, kurtosis

- Units: \( \frac{L}{t^2} \) i.e. dimensions \( \left( \frac{\text{ft}}{s^2}, \frac{\text{m}}{s^2} \right) \)

- Newton’s 2\textsuperscript{nd} Law: \( F = ma \)
Conclusion

- Turbulence is complex
- EDF and RMS leave out valuable information
- Three-axis method is instructive but hard to apply
- Average Vector method combines velocity magnitude, acceleration and rotation
- Actual data is required to further evaluate the Average Vector method
Collaboration

• Currently looking for collaborator(s) who would like to team up to test the concept. Specifically:
  • Biologists who can provide insight on delta t (response time of fish).
  • Field application. If you have a field test site where the concept can be applied as a comparison with other methods.
  • Create a team to write proposals/get additional funding to further test the concept.

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Classification of Vortices

THANK YOU

QUESTIONS/COMMENTS