Transition to turbulence in oscillating flows

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International Masters in Turbulence (M2)

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Contents

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Objective

Previous work

Methodology

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Questions
Introduction

Pure oscillating flow

Pulsatile flow
Introduction

Transition to turbulence in oscillating flow

Sub acoustic region

Acoustic Region

Mechanical probes (Hot wire anemometry)

Acoustic frequencies:

\[ \delta_v = 0.5\text{mm for } f = 20\text{Hz} \]
\[ \delta_v = 0.02\text{mm for } f = 20\text{kHz} \]
Objective

- Compare two different optical measurement techniques
  1. LDA
  2. PIV
- Focused on near wall region at high frequencies
1. Depicted from wiki
1. Depicted from wiki
Oscillatory boundary layer thickness is given by

\[ \delta_v = \sqrt{2\nu/\omega} \]

\[ \omega = 2\pi f \]

a. Reyt et al.
Experimental Setup (LDA)

LDV Measurements

- $f = 25 \text{ Hz}$
- Axial velocity along radius
- Radial dependence of axial component
- $\delta_\nu = 0.435 \text{ mm}$
- $Re_{\delta_\nu} = 64 \text{ to } 474^a$

\[ a. \text{ Reyt et al} \]
Acoustic boundary layer

Sine wave of frequency that propagates along x axis in cylindrical wave guide of radius R

\[ u_{ac}(x, r, t) = Ae^{i\omega(t-x/c)} \left( 1 - \frac{J_0(r\sqrt{-i\omega/\nu})}{J_0(R\sqrt{-i\omega/\nu})} \right) \]  \hspace{1cm} (1)
Acoustic boundary layer

Sine wave of frequency that propagates along x axis in cylindrical wave guide of radius R

\[ u_{ac}(x, r, t) = Ae^{i\omega(t-x/c)} \left( 1 - \frac{J_0(r\sqrt{-i\omega/\nu})}{J_0(R\sqrt{-i\omega/\nu})} \right) \]  \( (1) \)
Acoustic boundary layer

Acoustic velocity profile at different phases along acoustic period

- Experimental data
- Theoretical data

0 0.1pi 0.2pi 0.3pi 0.4pi 0.5pi 0.6pi 0.7pi 0.8pi 0.9pi pi

Re δv = 64

Re δv = 118

Re δv = 157

Re δv = 245
Acoustic boundary layer

Acoustic velocity profile at different phases along acoustic period

* Experimental data

- Theoretical data

<table>
<thead>
<tr>
<th>Phase (π/4)</th>
<th>Re ( \delta_v )</th>
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<tbody>
<tr>
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<td>0.2π</td>
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</table>
Acoustic boundary layer

Acoustic velocity profile at different phases along acoustic period for $Re_{\delta_v} = 260$ - Experimental data - Theoretical data

$0 \quad 0.1\pi \quad 0.2\pi \quad 0.3\pi \quad 0.4\pi \quad 0.5\pi \quad 0.6\pi \quad 0.7\pi \quad 0.8\pi \quad 0.9\pi \quad \pi$

$Re_{\delta_v} = 260$

$Re_{\delta_v} = 260$

(Changing $\theta$)
Acoustic boundary layer

Acoustic velocity profile at different phases along acoustic period after changing the value of $\nu$

- Experimental data
- Theoretical data

![Graph showing acoustic velocity profile at different phases along acoustic period after changing the value of $\nu$.]
Acoustic boundary layer

Acoustic velocity profile at different phases along acoustic period after changing the value of $\nu$

- Experimental data - Theoretical data

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<thead>
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<th>0.3pi</th>
<th>0.4pi</th>
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Re $\delta_{\nu} = 64$

Re $\delta_{\nu} = 118$
Acoustic boundary layer

Acoustic velocity profile at different phases along acoustic period after changing the value of $\nu$

- Experimental data

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- Theoretical data

$\text{Re} \delta_\nu = 64$

$\text{Re} \delta_\nu = 118$

$\text{Re} \delta_\nu = 157$
Acoustic boundary layer

Acoustic velocity profile at different phases along acoustic period after changing the value of $\nu$

Experiment data - Theoretical data

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Acoustic boundary layer

Acoustic velocity profile at different phases along acoustic period after changing the value of $\nu$

- Experimental data

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</tbody>
</table>
Acoustic boundary layer

Acoustic velocity profile at different phases along acoustic period after changing the value of $\nu$

- Experimental data
- Theoretical data

<table>
<thead>
<tr>
<th>$0$</th>
<th>$0.1\pi$</th>
<th>$0.2\pi$</th>
<th>$0.3\pi$</th>
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<td><img src="image2" alt="Graphs" /></td>
<td><img src="image3" alt="Graphs" /></td>
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$Re \delta_\nu = 64$

$Re \delta_\nu = 118$

$Re \delta_\nu = 157$

$Re \delta_\nu = 245$

$Re \delta_\nu = 260$

$Re \delta_\nu = 474$
Stokes boundary layer

With an increase in $Re_{\delta_{\nu}}$ we noticed the effective increase in boundary layer thickness.

Transition around $Re_{\delta_{\nu}} = 250$

$\delta_{\nu} = 0.435\text{mm}$

$Re_{\delta_{\nu}} = 64$ to 474
Experimental setup (PIV)

\[ f_s = 25 \text{ Hz} \]
\[ Re_{\delta_v} = 205 \text{ to } 466 \]
Methodology

Distribution of normalized Reynolds stress

3. Ramadan et all

Flat up to Re 240

Sudden change at Re 272

At Re 418 flow ~ fully turbulent
Velocity profiles

Acoustic velocity profile at different phases along acoustic period

- Experimental data

- Theoretical data

![Velocity profiles](image-url)
Velocity profiles

Acoustic velocity profile at different phases along acoustic period

- Experimental data
- Theoretical data

\[
\begin{array}{cccccccccc}
0 & 0.08\pi & 0.16\pi & 0.24\pi & 0.32\pi & 0.40\pi & 0.48\pi & 0.56\pi & 0.64\pi & 0.72\pi & 0.80\pi & 0.88\pi \\
\end{array}
\]

\[
\begin{array}{cccccccccc}
\text{Re } \delta_v = 205 & \text{Re } \delta_v = 240 & \text{Re } \delta_v = 272 & \text{Re } \delta_v = 302 & \text{Re } \delta_v = 336 & \text{Re } \delta_v = 375
\end{array}
\]
Velocity profiles

Acoustic velocity profile at different phases along acoustic period

- Experimental data

- Theoretical data
Acoustic boundary layer

Acoustic velocity profile at different phases along acoustic period for $Re_{\delta_v} = 272$:

- Experimental data
- Theoretical data

<table>
<thead>
<tr>
<th>Phase</th>
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<tbody>
<tr>
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<tr>
<td>0.08\pi</td>
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$Re_{\delta_v} = 272$

$Re_{\delta_v} = 272$ (changing $U$)
Velocity profiles

Acoustic velocity profile at different phases along acoustic period after changing the value of $\nu$.

- Experimental data
- Theoretical data

<table>
<thead>
<tr>
<th>Phase (rad)</th>
<th>0</th>
<th>0.08pi</th>
<th>0.16pi</th>
<th>0.24pi</th>
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Velocity profiles

Acoustic velocity profile at different phases along acoustic period after changing the value of $\nu$  

**Experimental data** - Theoretical data

<table>
<thead>
<tr>
<th>$\nu$</th>
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<th>0.16pi</th>
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Velocity profiles

Acoustic velocity profile at different phases along acoustic period after changing the value of $\nu$  

* Experimental data - Theoretical data

<table>
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<tr>
<th>$0$</th>
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20 février 2019
Results and discussions

Presence of spikes
Mean velocity around zero in regions of high accelerations

![Graph showing presence of spikes with mean velocity around zero in regions of high accelerations for different Reynolds numbers. The graph plots phases in radians against the mean velocity, with peaks indicating spikes.

\( \delta \nu \)

Re=205
Re=240
Re=272
Re=302
Re=336
Re=375
Re=418
Re=445
Re=466

Phases (in \( \pi \) radians)

0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00

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Results and discussions

Transition to turbulence in oscillating flows

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Results and discussions

Didn’t observe any coherent result
Comparison

Compared two quite similar cases using different optical methods
Comparison

Compared two quite similar cases using different optical methods
Comparison

Compared two quite similar cases using different optical methods

![Graph showing comparison between different optical methods for two cases.](image)
Conclusion and future work

- Compare two different optical measurement techniques
  1. LDA
  2. PIV

- Followed the methodology used in LDA methods

- Quantitatively the results seems similar for both the set of data but qualitatively the results are not comparable.

- Could be tried to get turbulent quantity out of LDA data
  1. Perform averaging over time, and we calculate S.D for these time slots
  2. It may represent turbulent intensity