Visualization of grid-generated turbulence in He II using PTV

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Talk outline

Background and Motivation
  Properties of He II
  Potential as experimental working fluid

Development of Visualization Experiment
  Particle tracking velocimetry
  Grid turbulence facility design
  Particle motion in turbulent He II

Characterization of He II Turbulence
He II is a non-classical fluid modeled by two fully miscible fluid components.

Low temperature phase diagram for helium-4

Second order phase transition from liquid He I to liquid He II at $T_\lambda \approx 2.17$ K

**Normal fluid** component (density $\rho_n$) is a classical Navier-Stokes fluid

**Superfluid** component (density $\rho_s$) is inviscid and carries no entropy
Cryogenic helium has potential in fluids research due to its extreme hydrodynamic properties.

He II has smaller kinematic viscosity than any other fluid ($\nu < 10^{-8} \text{ m}^2/\text{s}$) [1]

High Reynolds number flow ($Re = UD/\nu$) can be achieved in He II ($10^7 \text{ already achieved}$ [2,3])

Research suggests that mechanically driven flow behaves classically, but comprehensive evidence from simple, well controlled turbulence is lacking.

Develop a suitable technique to visualize turbulence in the wake of a towed grid.

Flow visualization offers high resolution and non-invasive flow field measurement

Fluid seeded with tracer particles that faithfully follow its motion

In this case tracer particles are solidified deuterium

Laser light sheet illuminates tracer particles in flow field

High-speed video camera records particle motion

Customized PTV algorithm identifies particles and resolves velocity field [1]

We have designed and constructed a device to visualize simple well-controlled turbulence in He II

<table>
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<tr>
<th>Flow channel</th>
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<tr>
<td><strong>Design Goals</strong></td>
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<tr>
<td>- Transparent imaging region</td>
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<tr>
<td>- Smooth uniform interior walls</td>
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<tr>
<td>- Instrumentation mounting</td>
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<tr>
<td><strong>Solutions</strong></td>
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<td>- Four-piece cast acrylic construction</td>
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<th>Mesh grids</th>
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<tr>
<td><strong>Design Goals</strong></td>
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<tr>
<td>- Generates homogeneous isotropic turbulence</td>
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<tr>
<td><strong>Solutions [1]</strong></td>
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<tr>
<td>- Less than 40% solidity</td>
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<tr>
<td>- Symmetric in channel walls</td>
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<tr>
<td>- Contact with channel isolated to corners</td>
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Linear grid motion is generated by a custom pulling system

Computer controlled stepper motor winds cable that pulls a linear drive shaft

Grid can be pulled through the channel at speeds from 0.1 to 60 cm/s with constant speed maintained for middle third of stroke

Edge-welded bellows seals grid drive shaft to cryostat throughout 30 cm stroke
We have achieved the goal of developing a system to visualize grid turbulence in He II

T = 2.0 K, \( v_{\text{grid}} = 30 \text{ cm/s} \), M = 3.75 mm

Playback is reduced to 30% of original speed
Visualization data will be used to characterize the turbulent flow and address some open questions about turbulence in He II

Some particle tracks extracted from the video (ensemble of \((x, y, t)\) coordinates)

Effective kinematic viscosity \(\nu'\) governs turbulent energy decay

\[ C_1 \frac{dL}{dt} + C_2 \frac{d}{dt} u'^2 = -\nu'(\kappa L)^2 \]

All quantities except \(\nu'\) are known or can be measured with our apparatus (\(u'^2\) was not accessible before flow visualization [1])

Energy spectrum \(E(k)\) describes kinetic energy distribution across turbulent eddies of different size

\[ E(k) = 4 \int_0^\infty \frac{u(t)u(t - \tau)}{u'(t)u'(t - \tau)} \cos(2\pi k \tau) d\tau \]  

Predictions for energy spectrum evolution exist [3,4] but \(E(k)\) has not yet been measured directly

Conclusions

Low kinematic viscosity of He II make it useful for simulating high $Re$ flow and testing models.

We have developed a novel experimental apparatus and applied the PTV technique to visualize turbulence in the wake of a grid pulled through He II.

Visualization results will play a key role in characterizing the behavior of turbulent flow in He II.

THANK YOU