Prepared for 2021 Virtual Grad Open House Poster Session

Characterization of Tunable Active Grid Generated Turbulence in a Water Tunnel Facility

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TEAMER Testing & Expertise for Marine Energy

*Financial support from NSF-CBET-Fluid Dynamics Program - Award #1706358

March 14, 2021 Bethlehem, PA

INTRODUCTION, PURPOSE, AND OBJECTIVE

- Active grid turbulence generating devices have been used to fine-tune turbulent flow environments in wind tunnel experiments.
- Active grids have seldom been used in water tunnels.
- Our laboratory has developed an active grid turbulence generator in a water tunnel with the goal of tailoring inflow turbulence to mimic flow conditions at high energy tidal test sites.

DEPLOYMENT OF TIDAL STREAM TURBINE[1]

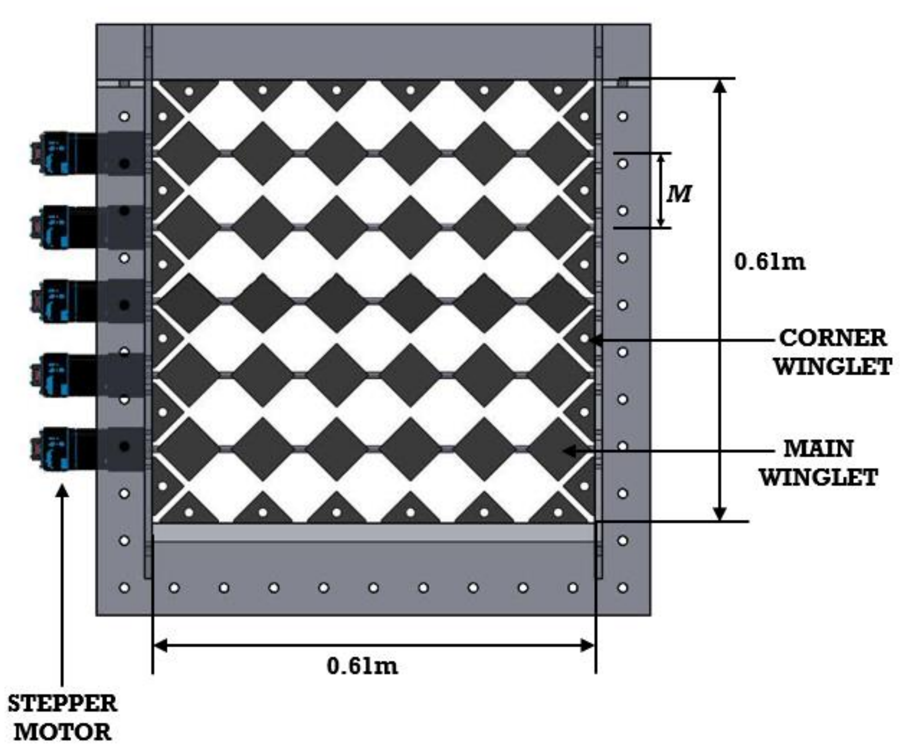
Purpose: Recreating turbulent flow conditions of tidal flows provides an opportunity for tidal energy industry associates and academics to test energy conversion devices in a low-risk, low-cost environment, compared to full-scale field endeavors.

Objective: Provide a detailed characterization of the turbulent flow tuned by an active grid turbulence generator in a water tunnel.

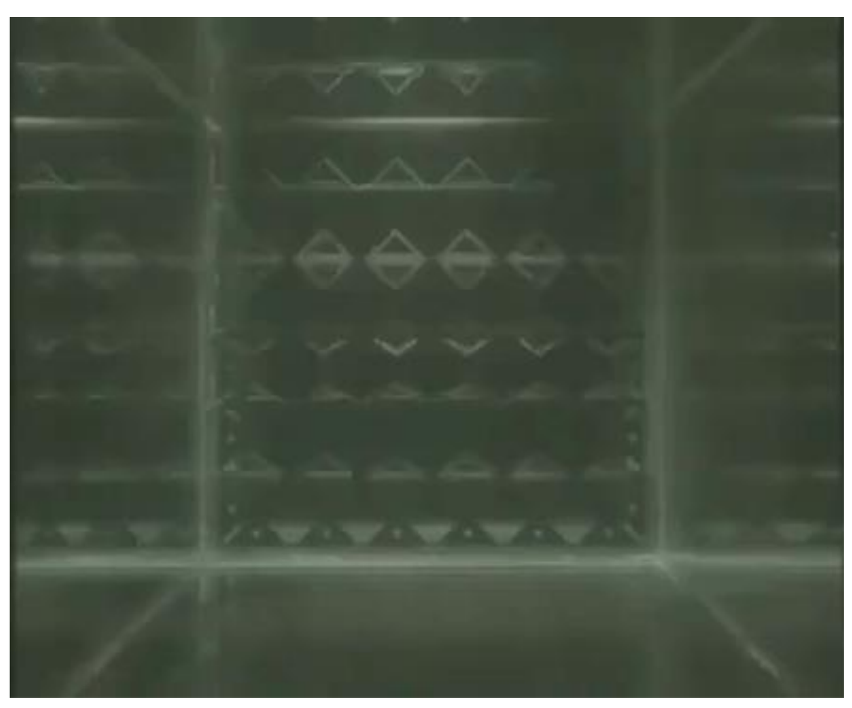
ACTIVE GRID TURBULENCE GENERATOR

ACTIVE GRID DESIGN AND OPERATING PARAMETERS

5-SHAFT ACTIVE GRID CONFIGURATION



ACTIVE GRID OPERATING IN WATER TUNNEL



- Lehigh Active Grid Turbulence generator has been developed
  - ✓ Has up to 10 rotating winglet shafts – 5 Horizontal + 5 Vertical – Bi-planar configuration.
  - ✓ 60 diamond shaped rotating winglets + 24 fixed half winglets.
  - ✓ Inner cross-section of 24” X 24”
  - ✓ Mesh size, *M*, of 4”
  - ✓ Each shaft controlled by a dedicated stepper motor
  - ✓ Three operating protocols for control: Synchronous (SN), Single Random (SR) and Double Random (DR)
- Diagnostics: An Acoustic Doppler Velocimeter (ADV) was used to characterize the turbulence parameters in the water tunnel facility.

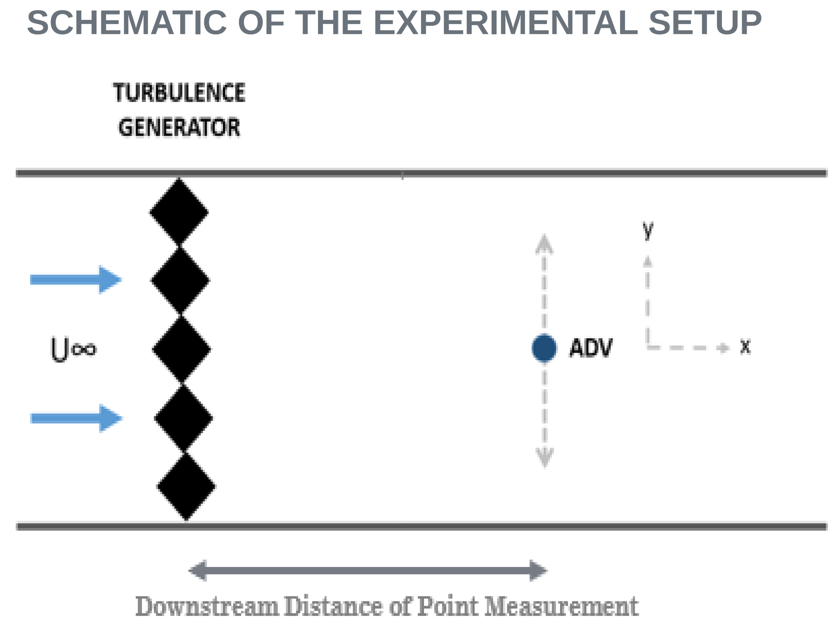
GRID PARAMETERS VARIED	
Operating Protocol	Synchronous, Single Random, Double Random
Winglet Geometry	Large, Small, Hollow
Freestream Velocity, U (m/s)	0.10, 0.20, 0.40, 0.60, 0.83
Angular Velocity, Ω (Hz)	0.10, 0.25, 1.00, 3.00

WINGLET GEOMETRY. NOTE THE SMALL WINGLET HALF THE SURFACE AREA OF THE LARGE WINGLET

ACTIVE GRID TESTING

EXPERIMENTAL SETUP

SCHEMATIC OF THE EXPERIMENTAL SETUP



- The active grid was set in a 5-shaft (30 winglet) configuration
- Grid parameters were varied one at a time, while holding all other parameters constant, isolating the effect of the variable at hand
- Velocity measurements were recorded in the center of the tunnel at 5 downstream locations: X/M = 2.5, 5.0, 10.0, 15.0, 17.5

EXPERIMENTAL RESULTS

TURBULENCE STATISTICS MEASURED

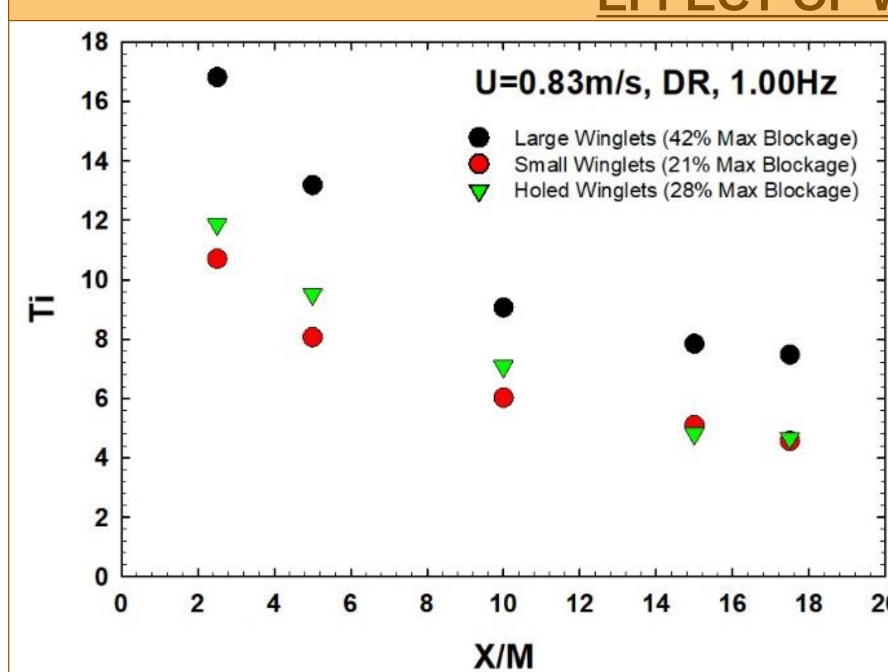
TURBULENCE STATISTIC	FORMULA
Turbulence Intensity, *Ti*	$Ti = \frac{u'_{rms}}{U} * 100$
Integral Length Scale, *ILS*	$ILS = U\int_0^T \frac{R(dt)}{R(0)}dt$
Taylor Reynold’s Number, Re_λ	$Re_\lambda = \frac{u'\lambda}{\nu}$
Anisotropic Ratio, I_{xy}	$I_{xy} = \frac{u'_{rms}}{v'_{rms}}$

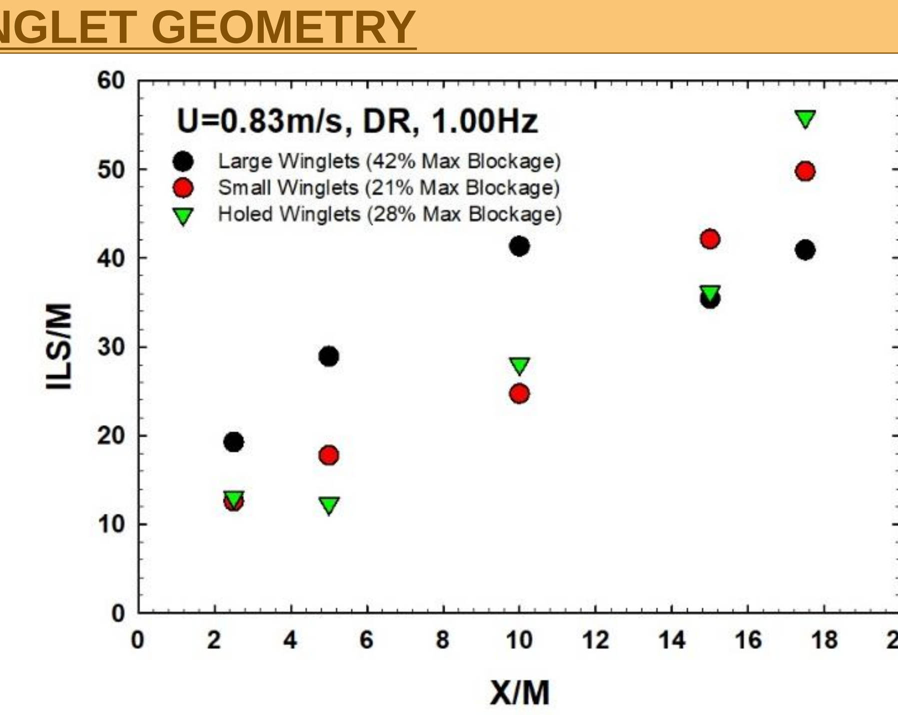
where:

- U – time-averaged streamwise vel.
- v' – streamwise vel. fluctuation
- v' – spanwise vel. fluctuation
- ν – kinematic viscosity
- $R(dt)$ – autocovariance function
- λ – Taylor microscale

Additional Nomenclature: Re_M – Mesh Reynolds Number, *Ro* – Rossby Number

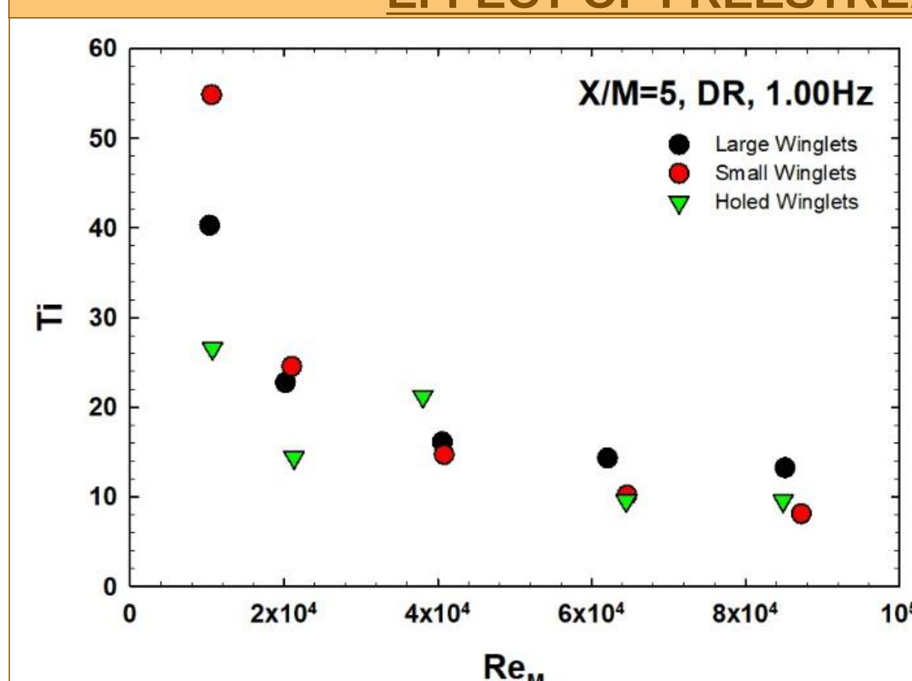
EFFECT OF WINGLET GEOMETRY

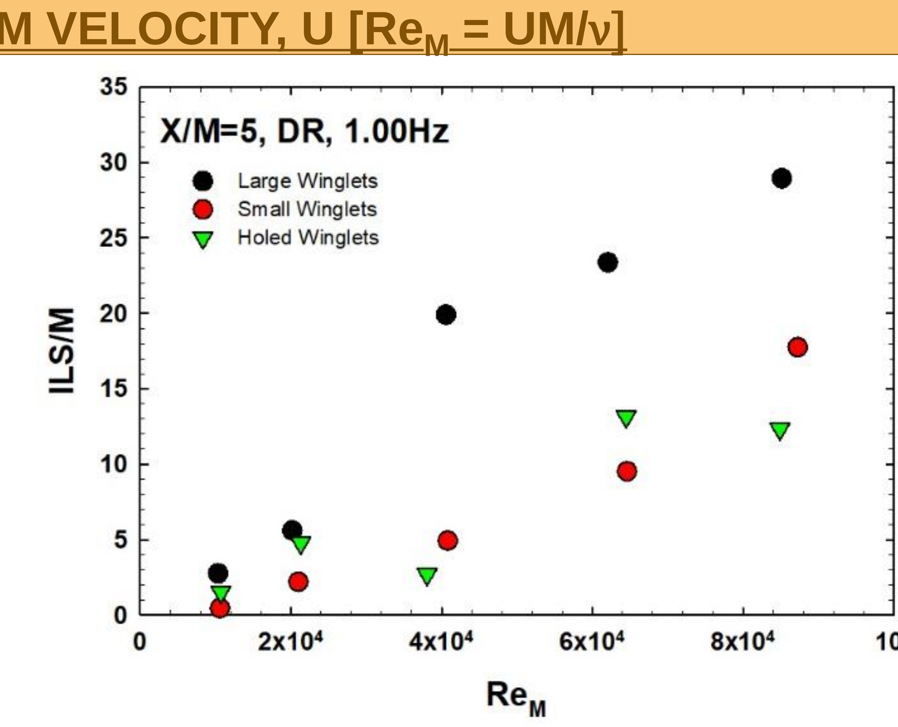




- Ti: Larger blockage → Larger Ti
- Re_λ: Larger blockage → Larger Re_λ
- ILS/M: No distinct trend
- I_{xy}: No distinct trend

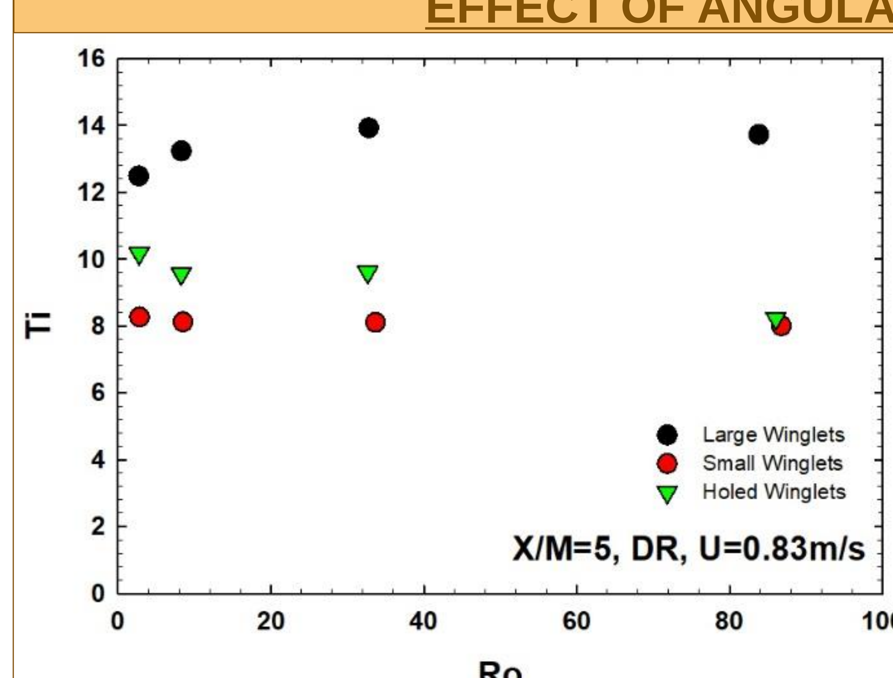
EFFECT OF FREESTREAM VELOCITY, U [Re_M = UM/ν]

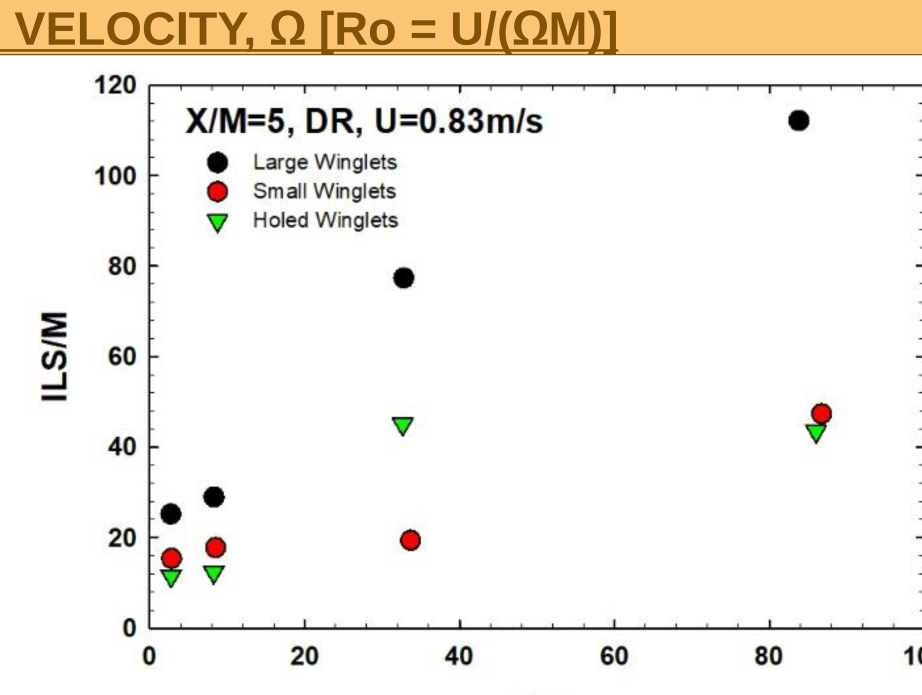




- Ti: Decreases until Re_M=20,000
- Re_λ: Monotonically increases w/ Re_M
- ILS/M: Continuously increases w/ Re_M
- I_{xy}: Decreases slightly with Re_M

EFFECT OF ANGULAR VELOCITY, Ω [Ro = U/(ΩM)]





- Ti: No significant impact
- Re_λ: No significant impact
- ILS/M: Continuously increases w/ Ro
- I_{xy}: No significant impact

CONCLUSIONS

- ✓ The three most influential active grid parameters effecting produced turbulence are the Rossby Number, the Mesh Reynolds Number, and the winglet blockage.
- ✓ Ti values remained constant as the integral length scales increase with increasing Ro; this indicates for a selected Ti value, one could alter Ω to tailor the large length scales of the flow.
- ✓ Re_M significantly influences Ti in active grid produced turbulence in water.

[1]Image courtesy of Verdant Power, Inc.