Numerical Simulation of Open Return Wind Tunnel and its Application in

Wind-bridge Deck Interaction Study

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The tug-of-war between Computational Fluid Dynamics and wind tunnel is sometimes taken as a zero-sum game with time as wind tunnel will be replaced by CFD, which is far from reality. Effectively, symbiotic use of both tools edges the competition. The development in computational power elevated the synergy between CFD and experiments. This dissertation presents the CFD works done by the author in Turner-Fairbank Highway Research Center laboratory. The works include wind flow characterization in a test section of the TFHRC wind tunnel, simplification of an existing complex wind tunnel model, and study of wind-generic bridge deck interaction. Wind flow characteristics were assessed by velocity distributions in the test area of the empty full scale wind tunnel. The complexity in the computational domain was eliminated by reducing the size of the tunnel, greatly reducing the computational time and cost. The realizable k-ε turbulence model was used as a closure for the Reynolds Averaged Navier-Stokes Equations (RANS) and Unsteady Reynolds Averaged Navier-Stokes Equations (URANS) equations. For all the simulations, commercial numerical code, Star-ccm+, was used.

Simulations with and without screens were analyzed. The presence of the screens produced a fairly uniform velocity distribution across the test section, and patterned

pressure distribution was also observed compared to screenless wind tunnel. A good agreement was obtained between the measured and calculated velocities. The open return wind tunnel was able to yield fairly uniform velocity distributions throughout the width of the test section. Ensuring removal of obstacles that can interfere the circulation of wind around the wind tunnel should not be undermined.

Floating number errors and geometry complexity were targeted during the simplification of the wind tunnel model. The computational size and time were reduced 45% and 40% respectively. Mesh sensitivity study was done to choose the correct discretized model. The computed velocity was found to be close to measured velocity.

Wind-bridge deck interaction was studied in the Reynolds number range of 4.25×10^4 - 4.29×10^4 for seven angles of attack ranging from -15^o to 15^o in an interval of 5^o. The aerodynamic response of the deck was numerically computed. URANS with implicit unsteady time steps was implemented. The calculated mean drag and lift coefficients were found to be close to the measured values. However, further work is recommended for the pitching moment coefficients, which aberrated from the wind tunnel testing results. The k-ε turbulence model was able to provide engineering results. The developed open circuit wind tunnel model lays the platform to studies such as the effect of aspect ratio of bridge decks and Reynolds number on aerodynamic performance.

Dedication

This dissertation is lovingly dedicated to my mother, Tsghereda Abraha. Her support, encouragement, and constant love have sustained me throughout my life.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ASM	Algebraic Stress Model
CFD	Computational Fluid Dynamics
CPU	Central Processing Unit
DES	Detached Eddy Simulation
DNS	Direct Numerical Simulation
EARSM	Explicit Algebraic Reynolds Stress Model
FDM	Finite Difference Method
FEM	Finite Element Method
FHWA	Federal Highway Administration
FVM	Finite Volume Method
HCC	Holland Computing Center
LEA	Linearised Explicit Algebraic (model)
LES	Large Eddy Simulation
LFD	Load Factor Design
NS	Navier-Stokes (Equation)
RANS	Reynolds Averaged Navier-Stokes

RNG	Renormalization Group (Method)
RSM	Reynolds Stress Model
SAE	Spalart Allmaras Equation
SGS	Subgrid Scale
SST	Shear Stress Transport
TDR	Turbulent Dissipation Rate
TFHRC	Turner-Fairbank Highway Research Center
TKE	Turbulent Kinetic Energy
TRACC	Transportation Research and Analysis Computing Center
URANS	Unsteady Reynolds Averaged Navier-Stokes
WSD	Working Stress Design
WSDOT	Washington State Department of Transportation
WT	Wind Tunnel
WTE	Wind Tunnel Extension

LIST OF SYMBOLS

Re	Reynolds number
C_d	Drag coefficient
C_l	Lift coefficient
F_d	Drag force
F_l	Lift force
a_{ref}	Plan projected area of the generic bridge deck
ρ	Density of air
B	Characteristic length, width of the generic bridge model
L	Length of the generic bridge model
V	Velocity of wind
α	Angle of attack
C_p	Pressure coefficient
V_{ref}	Reference velocity
P	Pressure
p	Time averaged pressure
P_∞	Reference pressure
K_{drop}	Pressure drop coefficient