Development of an Atmospheric-Boundary-Layer Profile at the NASA Langley Transonic Dynamics Tunnel

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Langley Research Center, Aeroelasticity Branch

Outline

- Research Objectives
- Test facility and brief history
- Determination of target profiles
- Design of atmospheric boundary layer hardware
- Test results
- Concluding remarks

Research Objectives

- Support wind-induced oscillation (WIO) testing of launch vehicles

- Supported objectives:
  - Quantify the impact of atmospheric boundary layer (ABL) upon WIO for launch vehicles
  - Quantify significance of aeroelastic scaling and Reynolds number
  - Compare wind-tunnel results to full-scale events
  - Determine best test practices for WIO testing

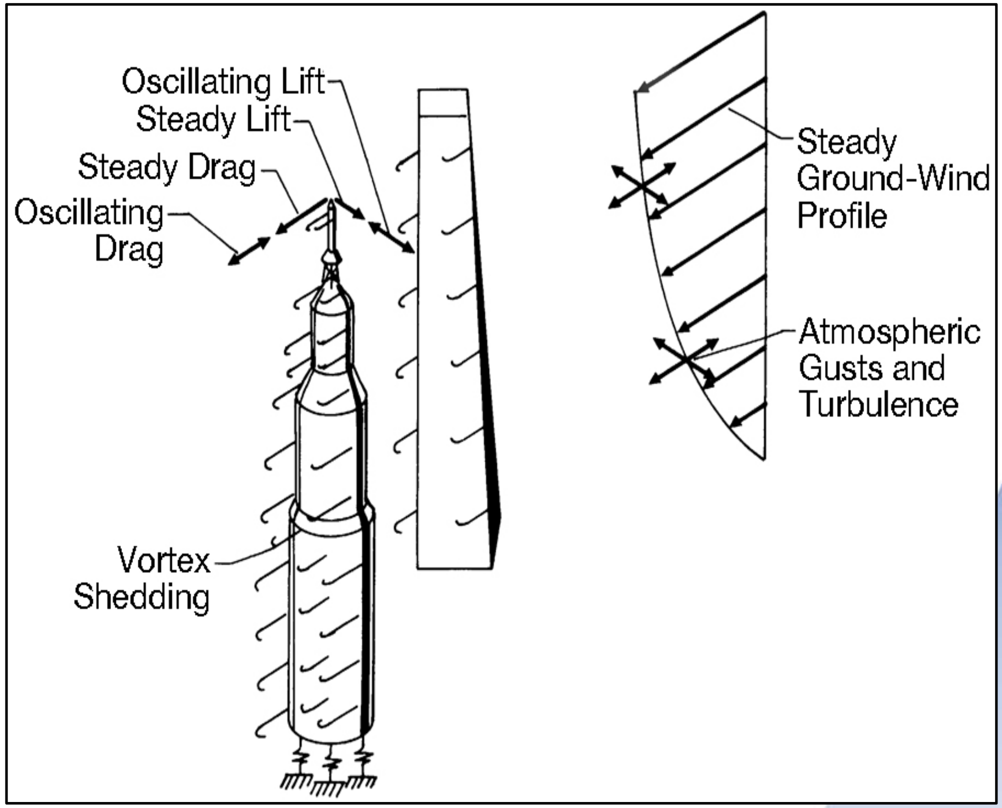


Image courtesy of NASA TM X 50548 [1]

Research Objectives

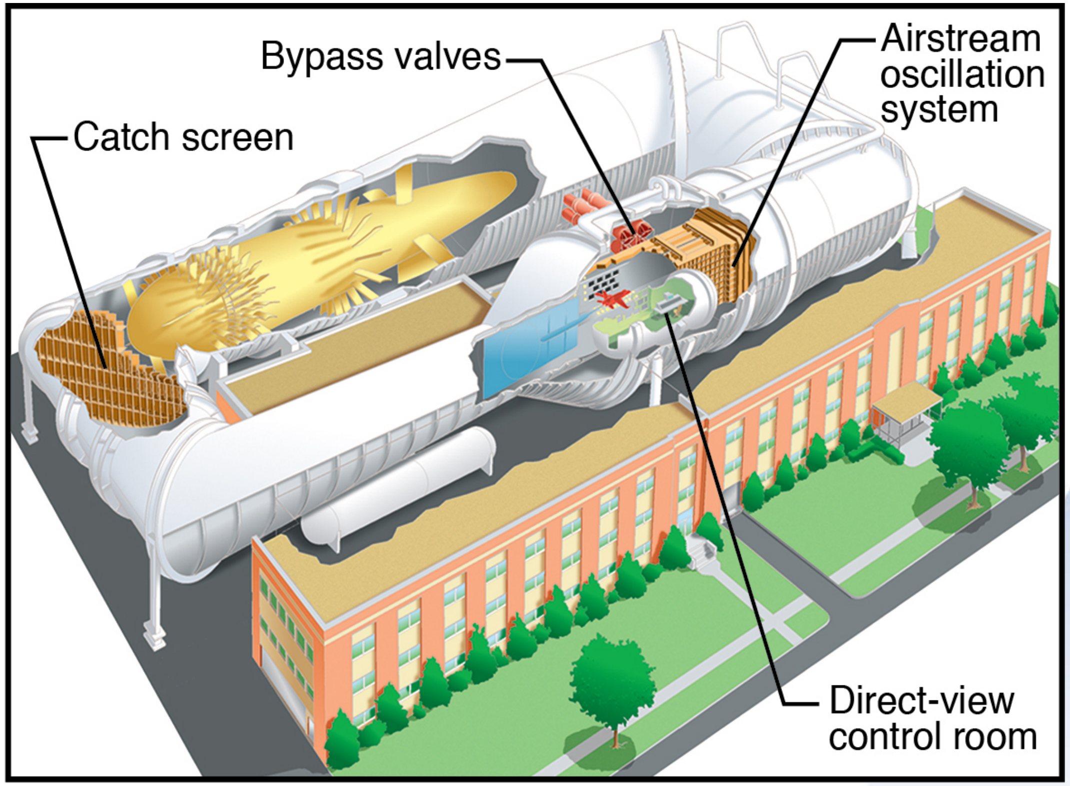
- Current research objective is to establish ABL testing capability

- Why does an ABL matter?
  - Believed to explain some discrepancies observed in simulation
  - Identified as an important contributor to dynamic response
  - Impact of turbulence to resonant WIO response is unknown, especially at flight-representative Reynolds number

- Define ABL characteristics:
  - Velocity Profile
  - Turbulence intensity
  - Turbulence frequency content
  - Uniformity of ABL throughout test volume

Test Facility, NASA Transonic Dynamics Tunnel

- Unique aeroelastic test facility
  - Large, variable pressure, R-134a or air test medium
  - Unparalleled ability to manipulate fluid-structure scaling parameters
  - Dynamically-scaled models at high Reynolds number
- Floor turntable for ground-wind loads (GWL) testing
- Used extensively during previous NASA GWL programs
- Previous attempts at ABL simulation (circa 1960s) unsuccessful
- ABL facilities since developed for civil engineering structures



ABL Target Profiles

- Simulations desired for 3 launch sites to replicate full-scale events of interest
  - Space launch complex 40 (SLC-40) at Kennedy Space Center (KSC)
  - SLC-39 at KSC
  - Launch site in Texas (SLC-TX)
- Each site at different elevation above the ground plane
- Sparse wind data exists at each site
- Define target velocity profiles:

$$V = V_{ref}\left(\frac{Z}{Z_{ref}}\right)^{\alpha}$$

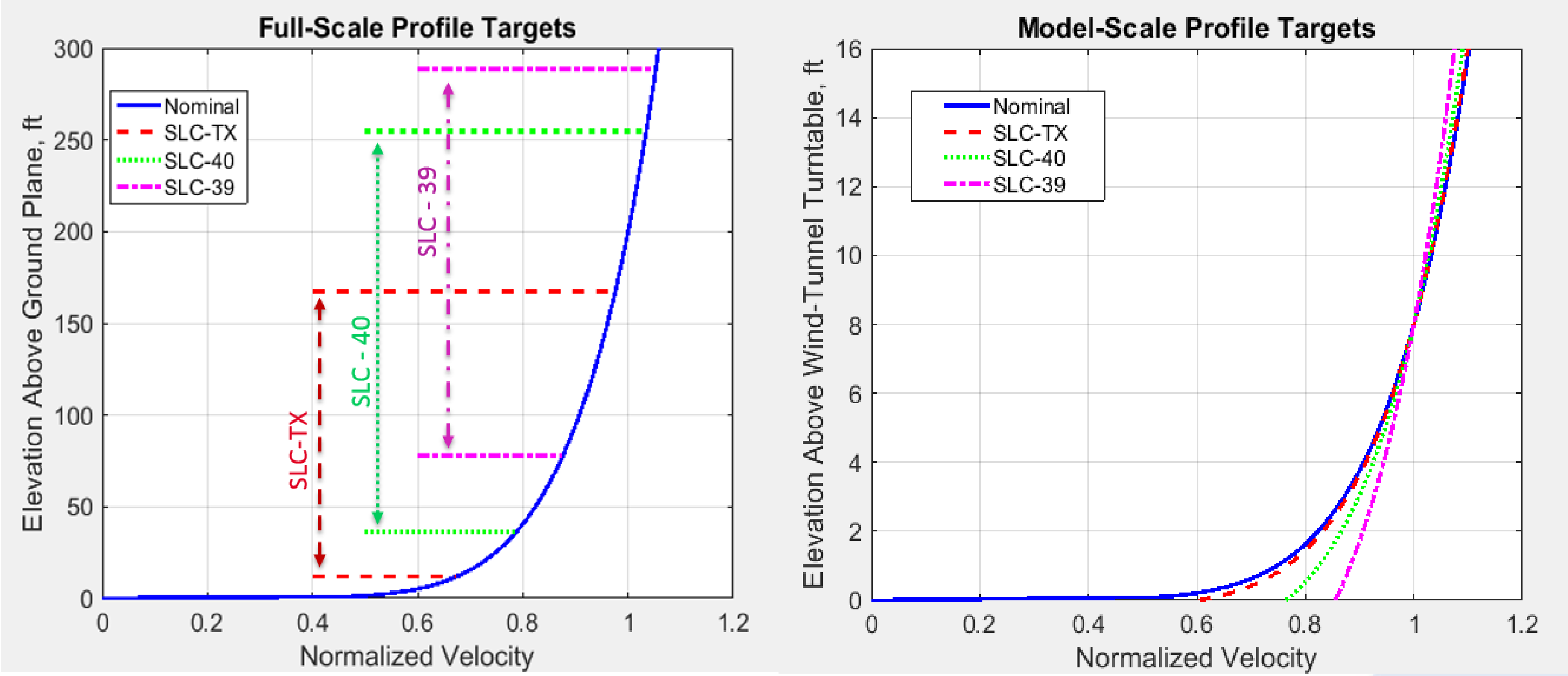
- *'Representative'* α = 0.14 established from launch site data, but varies

ABL Target Profiles

- Two design methodologies considered:
  1. Scale pad height and nearby structures above surrounding ground plane immersed in ABL
     - *one ABL development in tunnel*
     - *multiple launch site capability*
     - *small models have poor scalability/instrumentation*
  2. Alter boundary layer in the vicinity of vehicle model and neglect height above ground plane
     - *larger models,*
     - *flight Re*
     - *need multiple ABLs in tunnel*

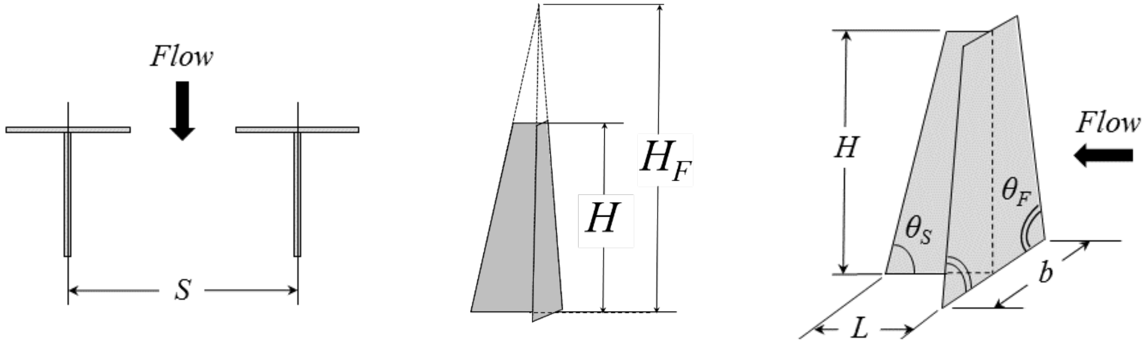
ABL Target Profiles

- Method 2 target profiles



Design of ABL hardware

- Leverage knowledge of ABL for civil engineering structures
- Irwin spires and floor roughness elements
- Spire design:



Design values for parameterized spires

Symbol	Description	Values: Spire A	Spire B	Spire C
H_F	Full isosceles triangle height	29.83 ft	30.13 ft	29.12 ft
H	Truncated height	16.0 ft	16.0 ft	16.0 ft
b	Base width of front plate	1.34 ft	0.85 ft	2.41 ft
S	Lateral spacing of spires	5.0 ft	5.0 ft	5.0 ft
θ_F	Base angle of front plate	88.71°	89.20°	87.63°

Design values for common splitter plate

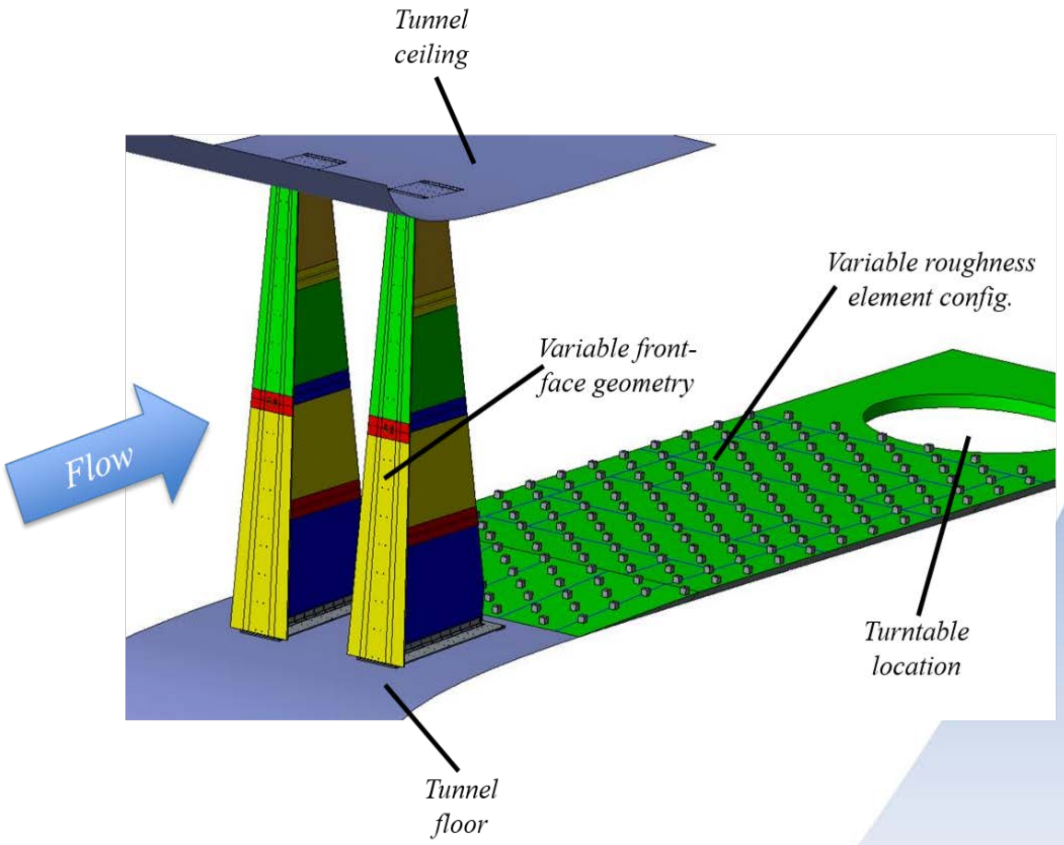
Symbol	Description	Value
L	Transverse splitter plate length	7.0 ft
θ_S	Trailing base angle of splitter plate	76.0°
H	Splitter plate height	16.0 ft

Design of ABL hardware

- Roughness elements:
  - Edge-length to spacing ratio, affects profile
  - Size, affects turbulence

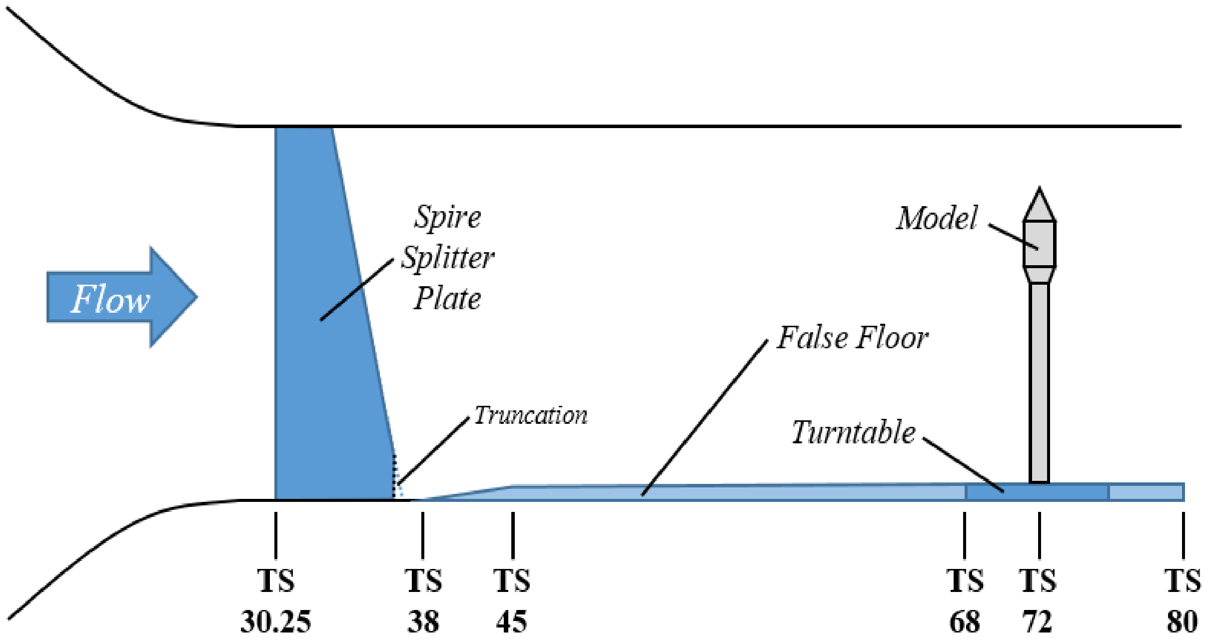
Roughness element sizing parameters

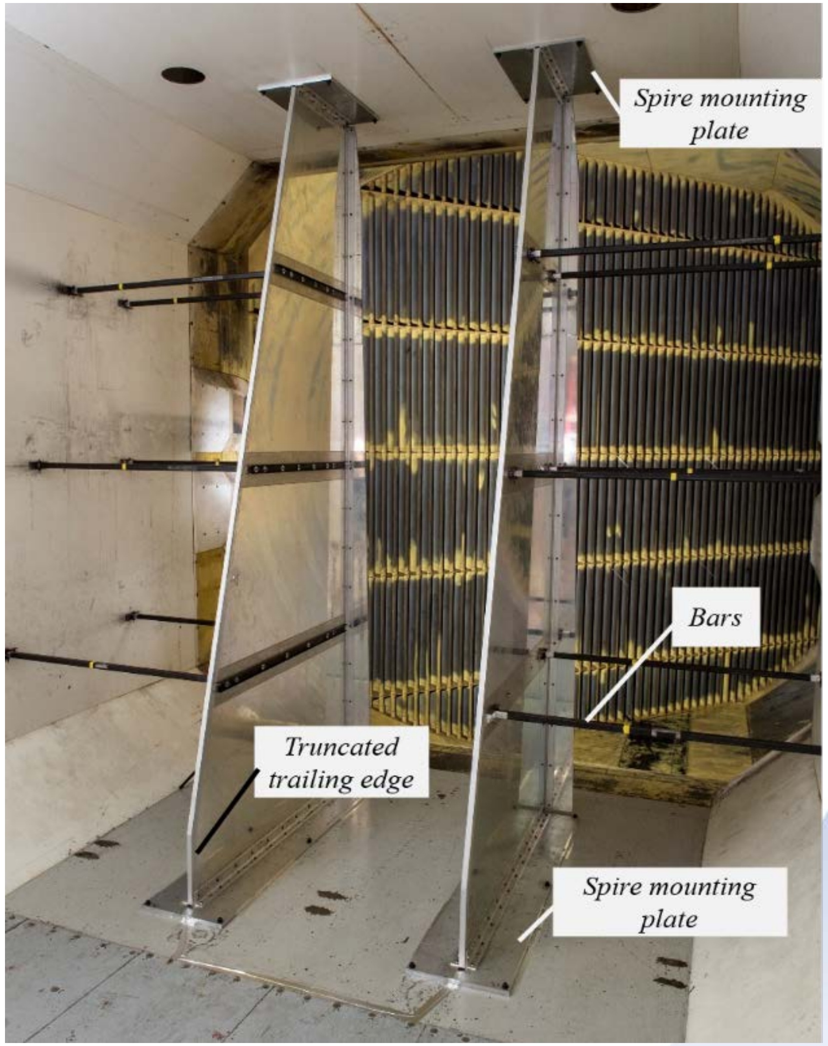
Symbol	*Description*	*Case Values*
E	Roughness element edge length (= height)	3.0 in. (= “Roughness A”) 6.0 in. (= “Roughness B”)
W	Lateral spacing between centers of neighboring elements	12 in. (Roughness A) 24 in. (Roughness B)



Design of ABL hardware

- Installation in tunnel
  - Removable, hand-carried
  - Lightweight, flexible
  - Required support bars

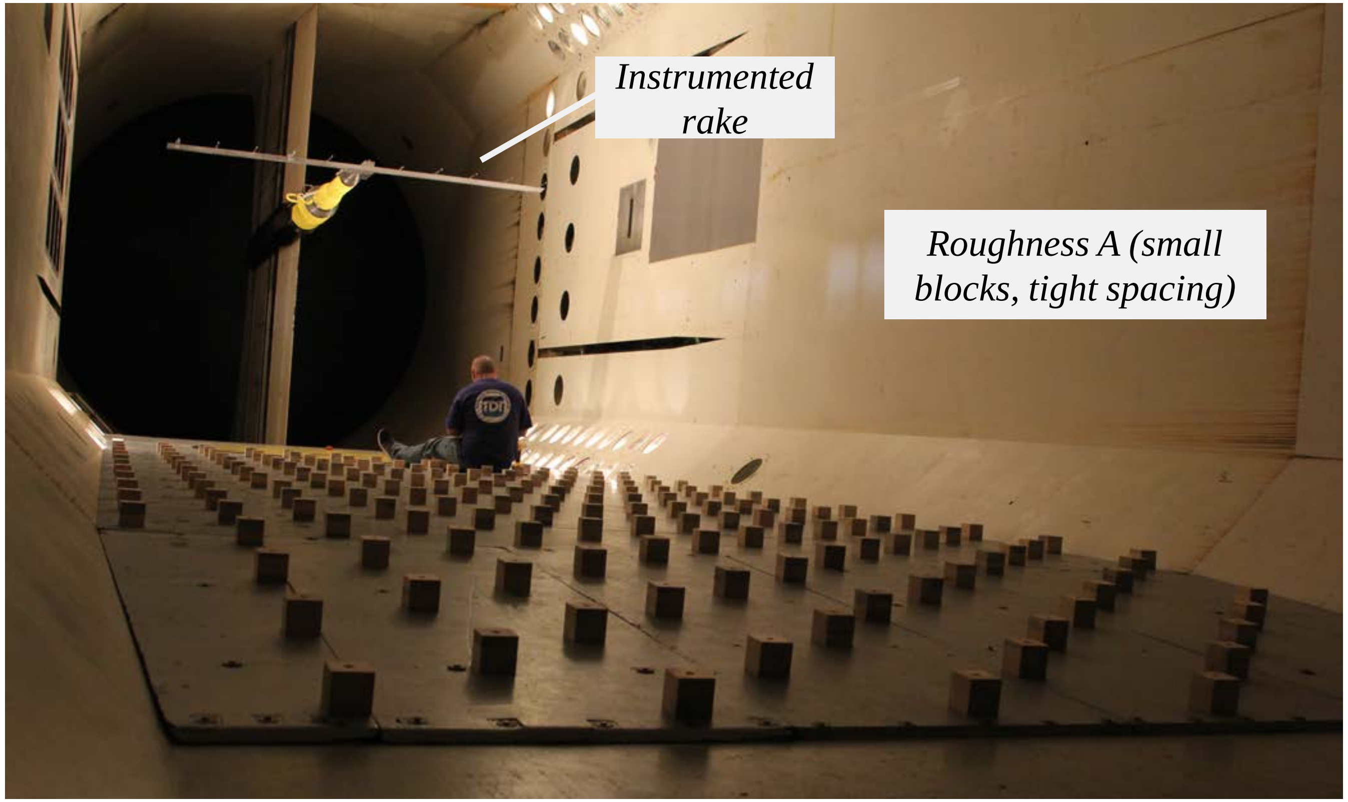


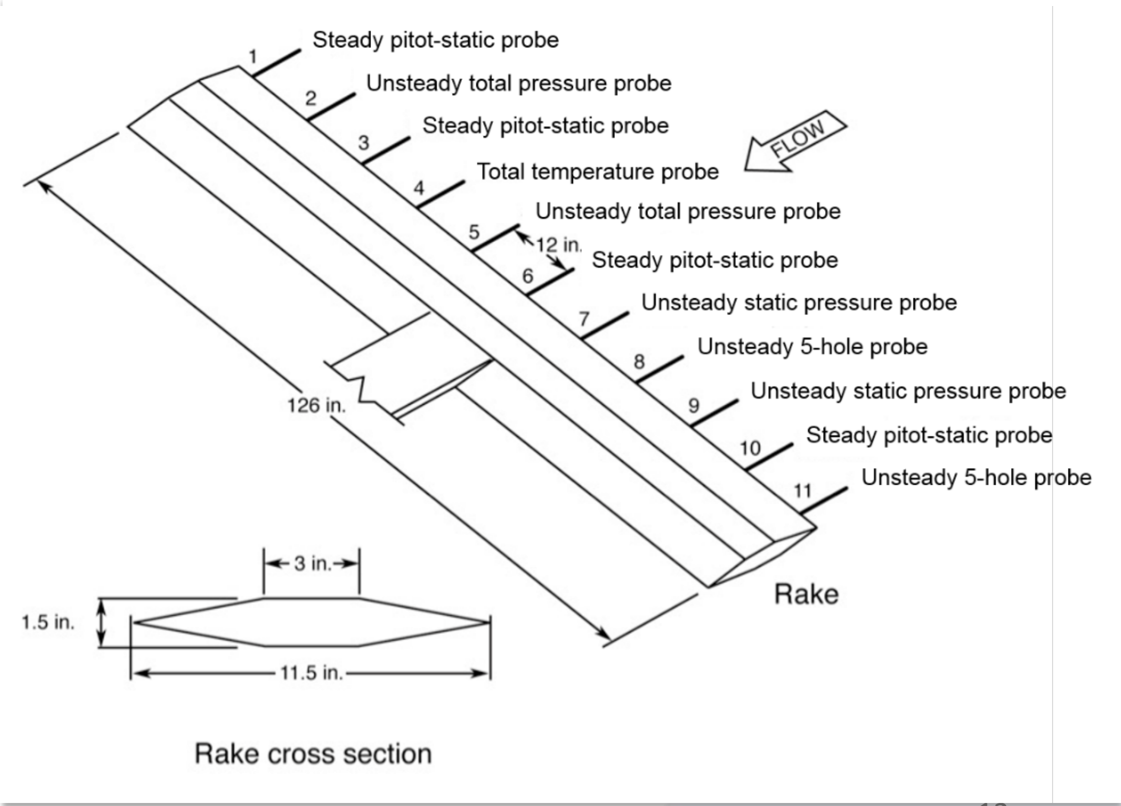


Instrumentation

- Instrumentation rake, mounted on sting
  - Vertical translation and rotation
  - Complementary instruments can be rotated to same position

- Steady pressure
- Unsteady pressure
- Unsteady 5-hole probes



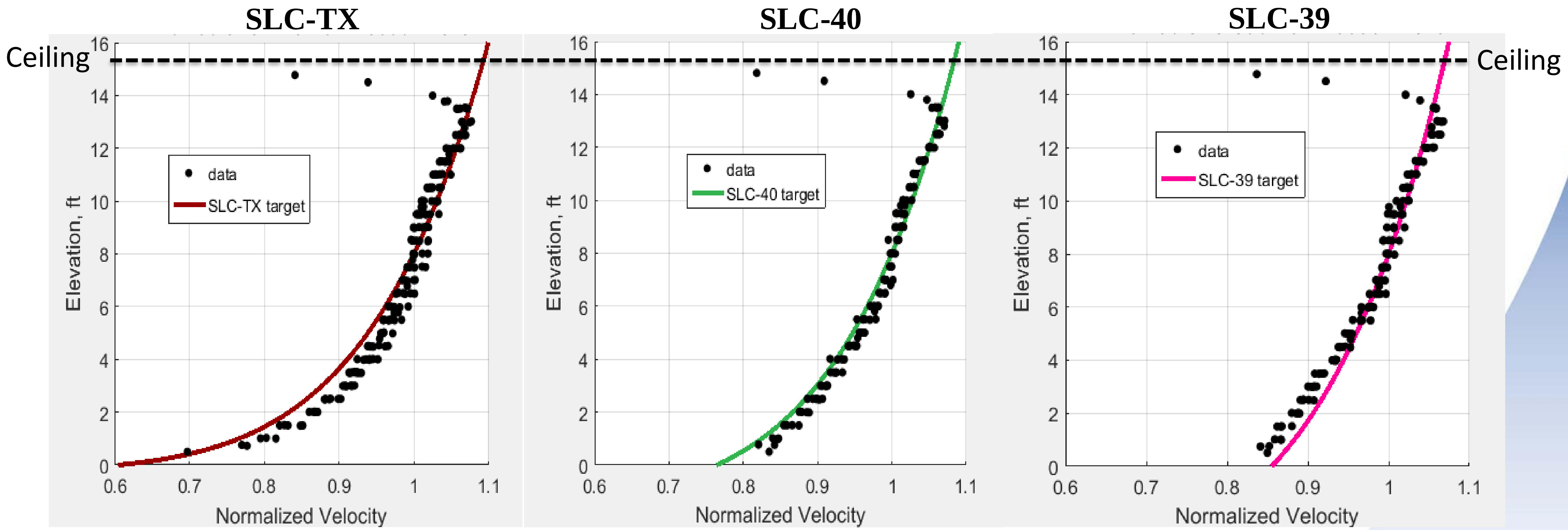


Test Results

- Quantified by:
  - Velocity profile
  - Lateral uniformity
  - Turbulence intensity and spectra
  - Degree of anisotropy

Test Results - *Profile*

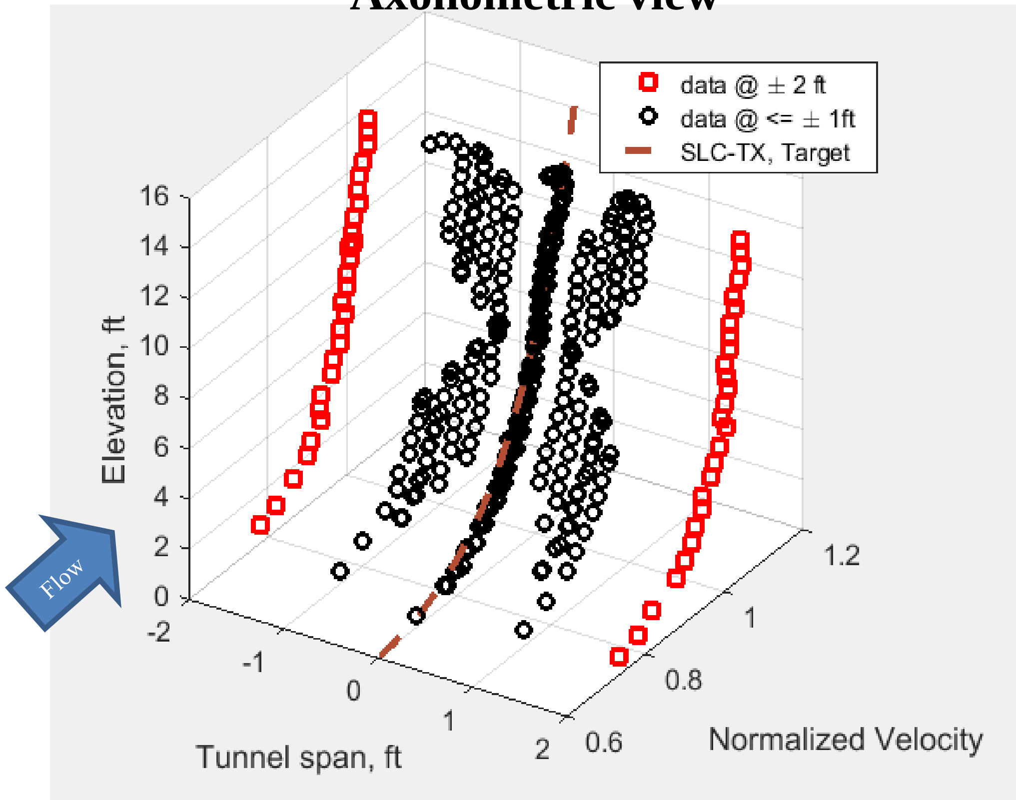
- Velocity profiles, measured on tunnel centerline
  Calculated from total pressure measurements and test-section static pressure



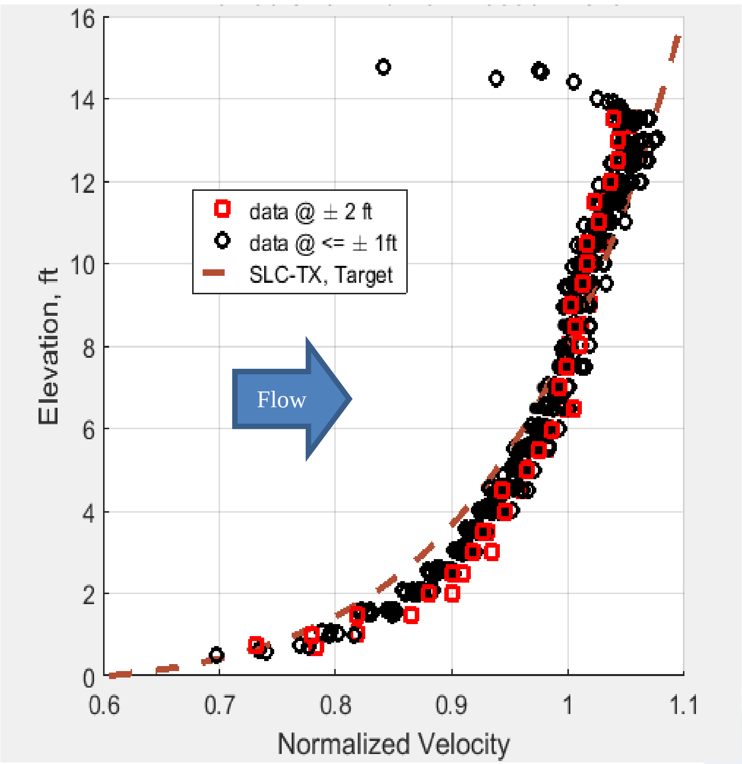
Test Results - *Lateral Uniformity*

- Lateral uniformity
  Acquired with various instruments at various sting roll angles

Axonometric view



Side view



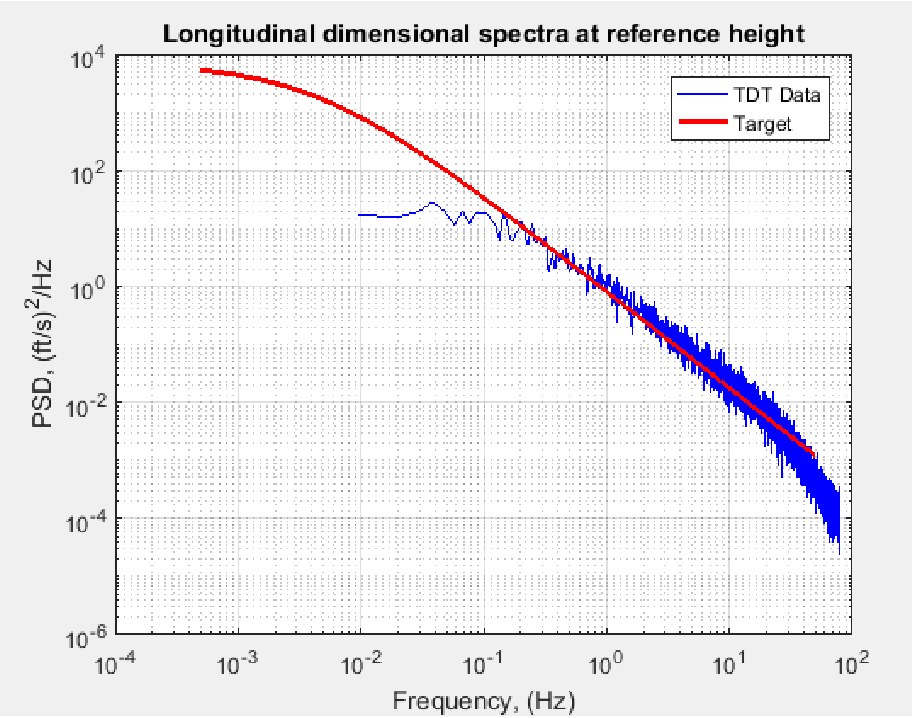
Test Results - *Turbulence Intensity, Spectra*

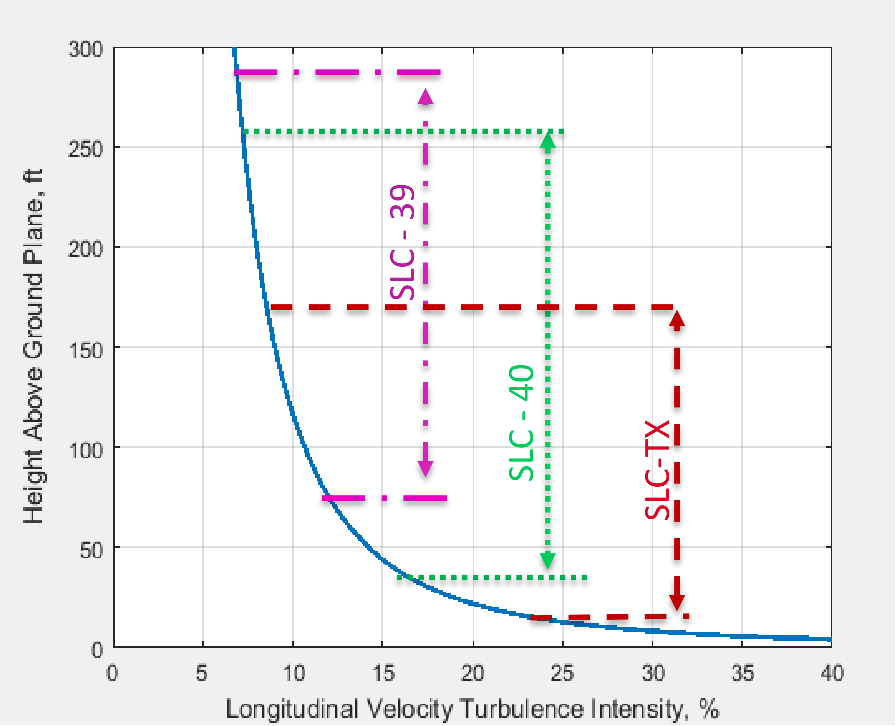
- Turbulence intensity and spectral content

  What should it be?

- Cannot determine from existing pad data
- Reference civil engineering measurements[19]
- Terrestrial environment criteria, guideline for aerospace vehicles, gives model for spectral content of velocity[16, 17]
  - Spectral content of turbulence is published
  - Turbulence intensity (standard deviation normalized by mean) can be derived

Test Results - *Turbulence Intensity, Spectra*





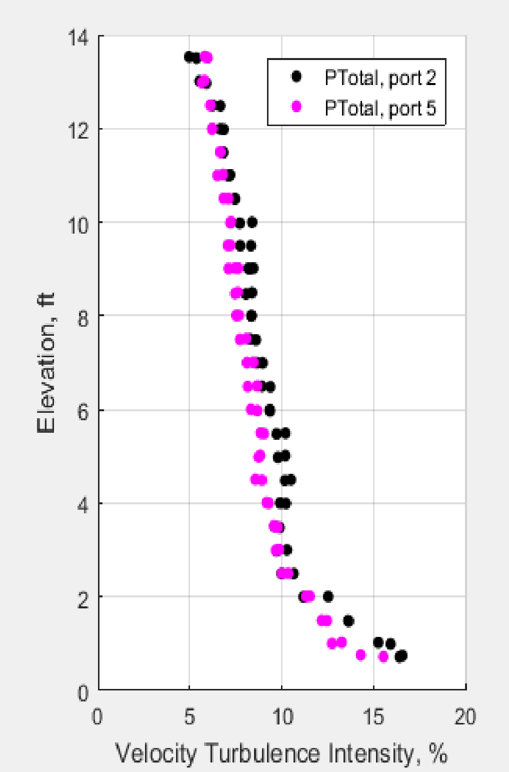
- Spectral content shows close match, except low frequency quasisteady values
- Intensity can vary significantly based upon time-scale selections
- Determined 8 to 20% intensity as representative target

Test Results - *Turbulence Intensity, Spectra*

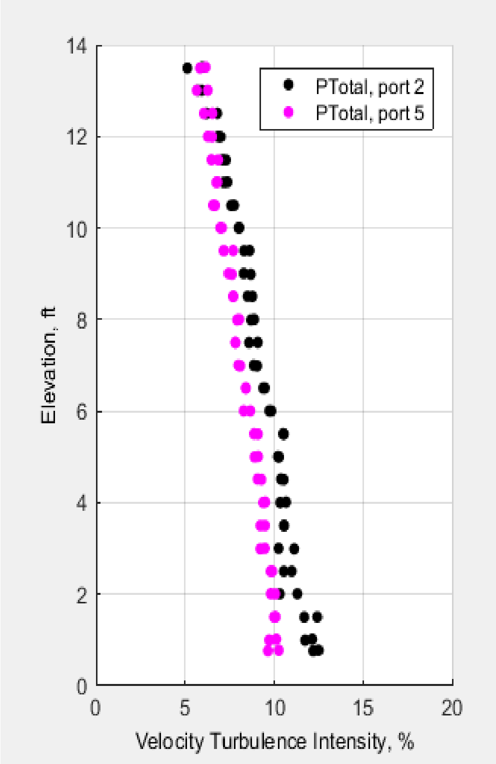
- Turbulence intensity

  Standard deviation of velocity, normalized by mean reference velocity

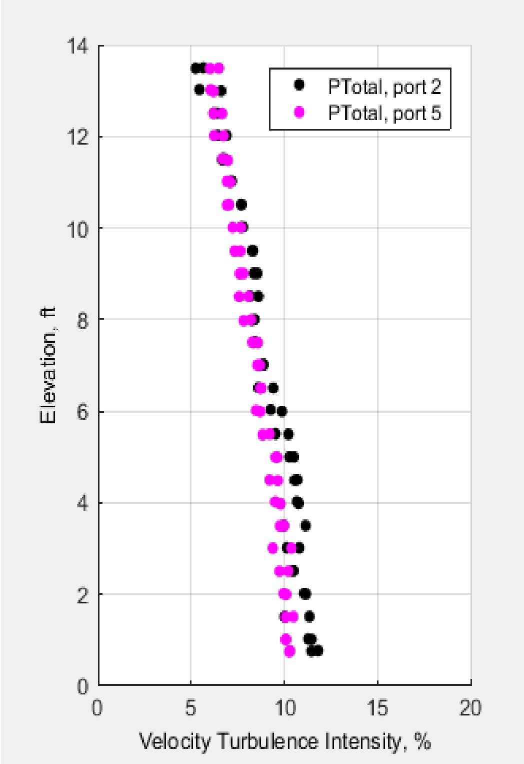
SLC-TX



SLC-40



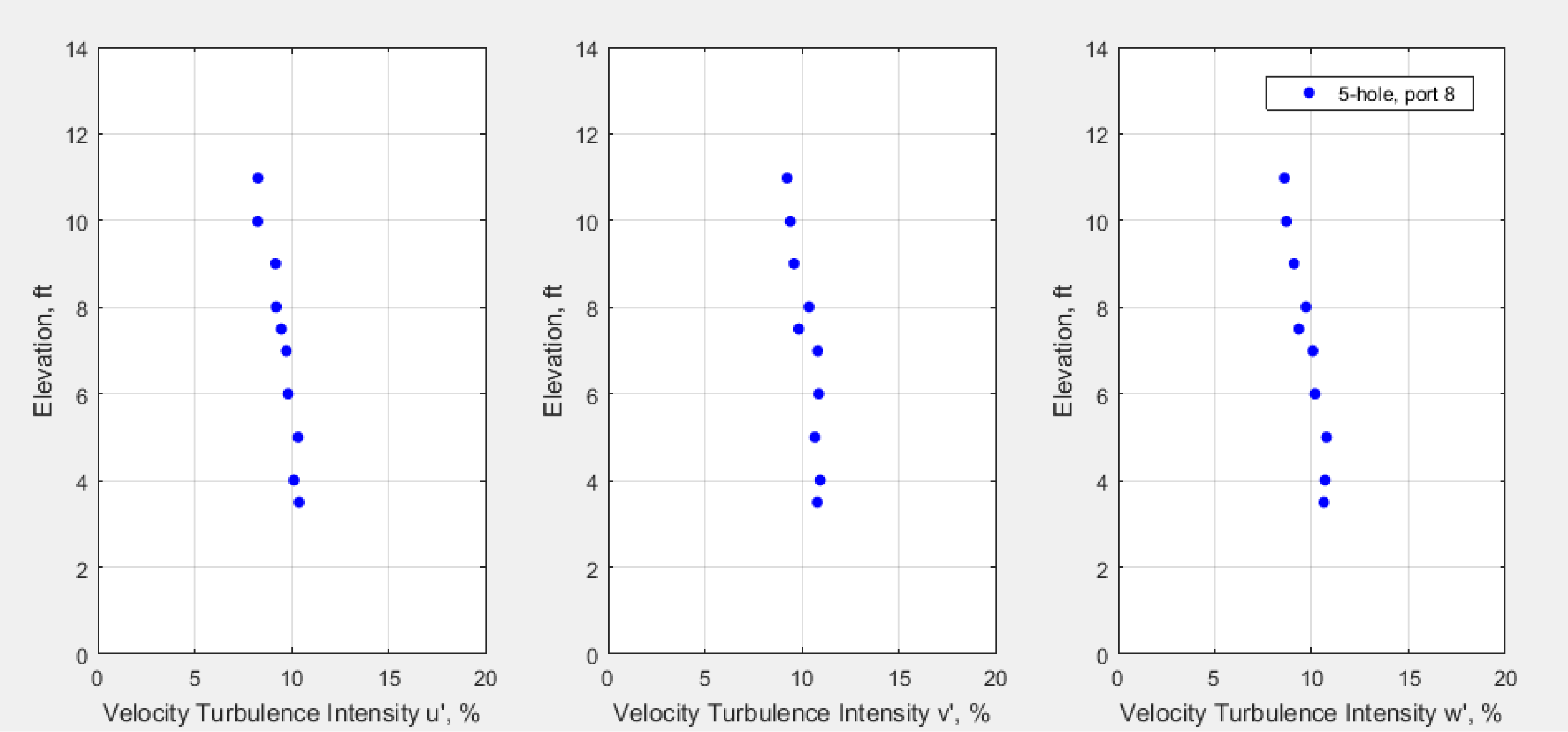
SLC-39



Test Results - *Degree of Anisotropy*

- Adequate simulation should show similar intensity in varying axes
- Can determine velocity turbulence intensity in x, y, z, from unsteady 5-hole probes
- Data acquired at the centerline

x-direction (*u'*) **y-direction (*v'*)** **z-direction (*w'*)**



Concluding Remarks

- ABL test capability was developed in the NASA Langley TDT
- Successful replication of:
  - Velocity profile
  - Lateral uniformity of profile
  - Turbulence intensity
  - Spectral content of turbulence
  - Establishment of isotropic turbulence

- Enables dynamic aeroelastically-scaled launch vehicle models to be tested at flight Reynolds numbers in representative ABL profiles

Questions?

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