Inlet Performance of the NFAC 1/50th-scale 80- by 120- Foot Wind Tunnel

Hannah T. Dromiack*
Science and Technology Corporation, NASA Ames Research Center, Moffett Field, California, 94035, USA

Lauren N. Wagner†
NASA Ames Research Center, Moffett Field, California, 94035, USA

The National Full-Scale Aerodynamics Complex 80- by 120-Foot Wind Tunnel (80x120) was dedicated in 1987 and rated at 100 knots for full-scale aircraft testing at NASA Ames Research Center. The 80x120 is the world's largest wind tunnel, designed as an open circuit tunnel with a large aerodynamically treated inlet open to the ambient atmospheric air. In 2017, damage was sustained within the wind tunnel drive system, opening a window to do testing using the existing 1/50th-scale model of the 80- by 120-Foot Wind Tunnel within the full-scale 80- by 120-Foot Wind tunnel test section. The objective of the research was to quantify the turbulence levels within the 1/50th-scale test section as a function of onset atmospheric wind direction (± 90 deg from tunnel center-line), variable test section speed (5 – 50 m/s) and purposeful obtrusion of wind flow into the inlet. The model wind tunnel inlet, contraction, and test section are geometrically identical to that of the full-scale wind tunnel and model testing provides aerodynamic performance characteristics under controlled test conditions allowing for insight into the full-scale test section flow quality. The test section turbulence levels are minimally affected by the onset direction of the ambient atmospheric wind, but are dramatically affected by the speed in the tunnel while operated in the presence of winds. Original design specifications were axial/vertical/lateral turbulence ≤ 0.5% at maximum test section speed, though early full-scale tunnel testing determined that lateral turbulence would be ≤ 0.6%. For test section speeds ≥ 30 m/s the tunnel is within the design specification limits. Between 5 m/s and 30 m/s, the test section turbulence levels are dependent on the onset wind direction and test section speed where test section turbulence in the axial, vertical and lateral directions was seen to be between 0.5% and 1% and, at times, greater than 1%. Finally, testing was performed with blockage designs at the inlet to disrupt the wind flow quality entering the tunnel contraction zone in an attempt to create higher levels of turbulence for high turbulent test conditions simulating the earth's boundary layer. The highest turbulence levels measured were 6% in the axial direction by use of large spires designed to obstruct ≈ 50% of the inlet area.

I. Nomenclature

80x120	=	80- by 120-Foot Wind Tunnel
I_{uu}	=	relative axial turbulence intensity %
I_{vv}	=	relative lateral turbulence intensity %
I_{ww}	=	relative vertical turbulence intensity %
I_{uvw}	=	relative overall turbulence intensity %
NFAC	=	National Full-Scale Aerodynamics Complex
V_{wind}	=	ambient wind velocity
V_{ts}	=	test section velocity
Ψ	=	turntable yaw angle

*Research Associate, Aeromechanics Branch, and AIAA Student Member
†Pathways Intern, Aeromechanics Branch, and AIAA Student Member

Presented at the AIAA Science and Technology Forum and Exposition (AIAA SciTech Forum), Virtual, January 11-15 & 19-21, 2021.

II. Introduction

A. Facility Design

The National Full-Scale Aerodynamics Complex (NFAC) comprises of two wind tunnels, the closed circuit 40- by 80-Foot Wind Tunnel and the open circuit 80- by 120-Foot Wind Tunnel (80x120). Both wind tunnels share a common drive system; Fig. 1 shows the planview of the complex.

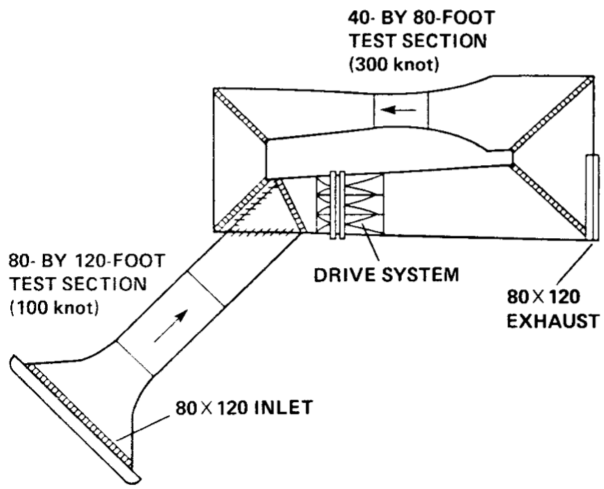

Fig. 1 Diagram of planview of the NFAC.

The 80x120 was designed based on conventional flow quality criteria determined by Mort et. al. in 1972 [1]. This criteria for a non-return wind tunnel was turbulence ≤ 0.5% in the axial direction at a maximum operating speed of 51.4 m/s (100 knots). The largest concern with building a non-return tunnel was the effects of prevailing winds on flow quality within the test section. In the late 1970s, tests were performed with a 1/50th-scale model of the complete 40x80/80x120 wind tunnel complex with a variety of different inlet treatments in an attempt to reduce these effects [2]. From these studies, it was determined that a minimal protection design was required to meet acceptable criteria for operation and wind tolerances were theoretically determined for a minimum protected inlet, as shown in Fig. 2.

Based on these earlier studies the 80x120 tunnel was designed to have a bell shaped inlet (40 m x 110 m) with minimal aerodynamic treatment and with a relatively short contraction zone forward of the test section. The 80x120 uses a semicircular inlet cowling on three sides. The inlet includes 102 splayed vertical guide vanes with 23 horizontal splitter plates designed to direct the airflow down the tunnel's center-line and provide uniform flow in the test section. On the trailing edge of the inlet's guide vanes is an aerodynamic treatment screen used to reduce the level of flow turbulence introduced by the vanes and splitter plates. An additional flow treatment is provided by a mesh screen on the leading edge of the vanes to keep birds out of the tunnel. Prior to tunnel operation in 1987, an interior flat-walled contraction zone was built inside the original bell mouth superstructure. Design goals included having I_{uu}, I_{vv}, and I_{ww} be ≤ 0.5% on the center-line for winds up to 7.7 m/s (15 knots) [3]. For greater detail on the design of the inlet see Ref. [3]. An aerial view of the 80x120 tunnel is shown in Fig. 3.

B. Atmospheric Winds

Measurements of atmospheric wind speed and direction made in front of the NFAC 80x120 inlet by Zell during a FLOCAL (flow uniformity and calibration) test are reported in Ref. [4]. At the time of the FLOCAL measurements, the weather tower was located 100 m (328 ft) upstream from the inlet face and 8.23 m (27 ft) east of the tunnel center-line with measurement stations 9.14, 18.28 and 30.48 meters (30, 60 and 100 feet) above ground level. Wind measurements provided by the 30.48 meter (100 ft) weather tower station were used to create the wind rose shown in Fig. 4 (Fig. 56 of Ref. [4]). This wind rose has been rotated 76.7 degrees so that true north is at the top of the page showing that the winds are mostly from the northwest between 0 and 8.94 m/s (20 mph) and illustrates that the wind tunnel is, unfortunately, well aligned with prevailing winds at the site.

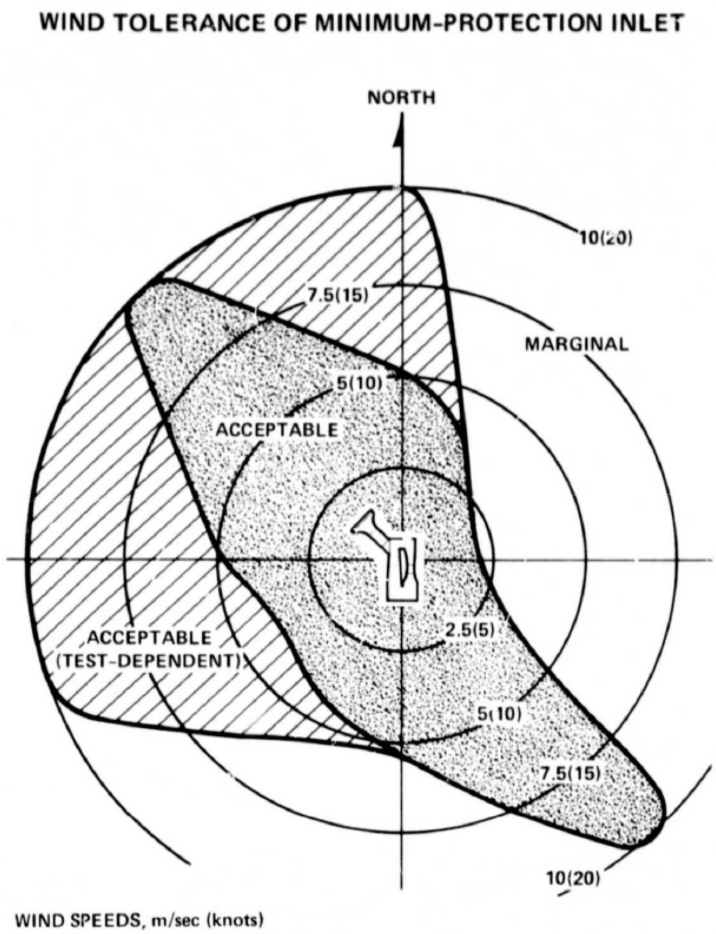

Fig. 2 Wind tolerance regions for V_{ts} > 46.3 m/s (90 knots) (Ref. 2).

C. Prior 1/15th-Scale Model Testing

The design and experimental testing leading to the full-scale design is presented by van Aken et. al. [3] along with results from initial full-scale running of the 80x120. Testing included a 1/15th-scale model of the 80x120 wind tunnel, with test section airspeed limited to 41.2 m/s (80 knots). Figure 5 presents the full-scale data for I_u test section turbulence measured at both full-scale and 1/15th-scale (Ref. [3], Fig. 17). I_u is calculated by the root mean square fluctuation of the wind velocity divided by the axial wind velocity while I_{uu} is the root mean square fluctuation of the wind velocity divided by the mean wind velocity. In previous studies, I_u was the metric when looking at operational limits though I_{uu} is used instead within this analysis. Zell showed that there was no discernible difference between lateral and vertical turbulence intensity measurements in the NFAC 80x120 test section and claimed the high levels of lateral and vertical turbulence intensity compared to axial turbulence intensity were typical of subsonic wind tunnels [4]. Full-scale measurements with V_{ts} > 90 knots are plotted as solid symbols in Fig. 5 and show turbulence intensity I_u to be independent of V_{wind}/V_{ts} for V_{ts} close to maximum tunnel speed. This implies that test section relative turbulence intensity is independent of external wind level for high test section velocities. Since the open symbols refer to full-scale measurements for V_{ts} < 90 knots, it is clear that increased test section turbulence can be expected at times for lower test section velocity. Without more information, no conclusions could be reached regarding the sensitivity of test section turbulence to V_{wind}/V_{ts} at reduced tunnel speed.

Agreement was found in this study between the theoretical expectations, model testing and the full-scale testing of the tunnel. The results of the 1/15th-scale model predicted the full-scale turbulence levels to be $I_{uu} \approx 0.4\%$ and $I_{vv} \approx$

Fig. 3 Aerial View of 80- by 120-Foot Wind Tunnel Inlet.

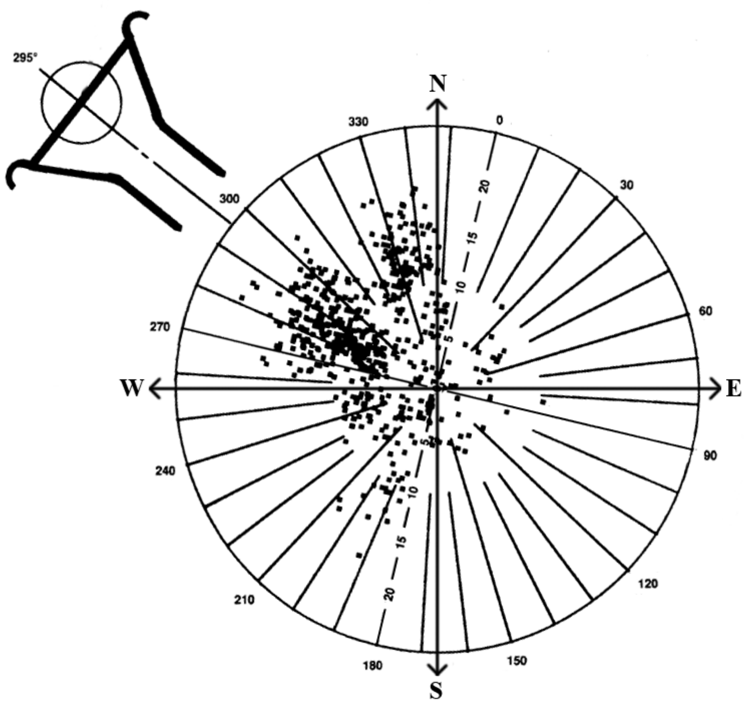

Fig. 4 Wind rose for 80x120 wind tunnel inlet (Ref. [4], Fig. 56).

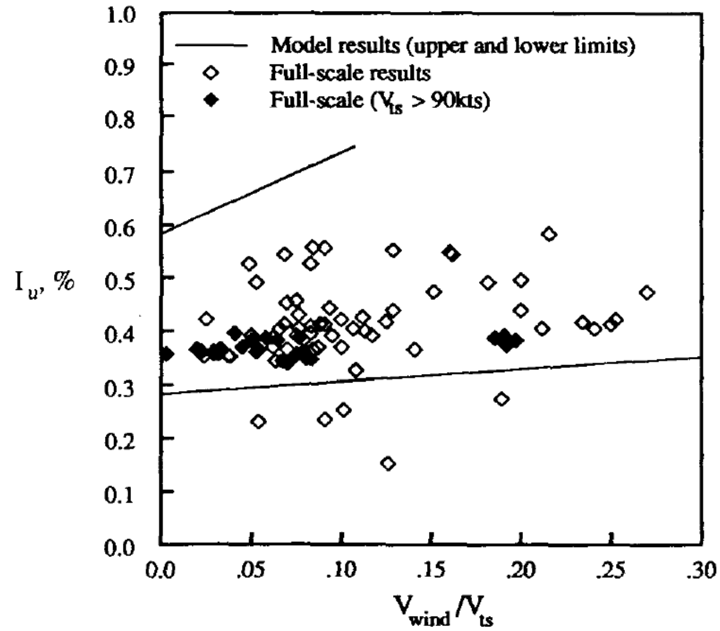

Fig. 5 Effect of atmospheric wind on relative turbulence intensity level in 1/15th-scale and full-scale 80x120-wind tunnel (Ref. [3], Fig. 17).

0.6% with a test section velocity > 46.3 m/s for ambient winds < 7.7 m/s. This agreed with experimental results from full-scale testing. It was also theorized that the differences in results between model testing and full-scale testing were due to where in the earth boundary layer the two were operating, the difference in relative size of wind eddies, and the difference in exhaust configurations, although agreement between results show these to be close to negligible effects [3]. It is important to note that the 1/15th-scale inlet testing did not study the effect of controlled wind speeds or different onset wind directions since the facility was dependent, as is the full-scale facility, to the existing atmospheric wind conditions occurring during testing.

The 80- by 120-Foot Wind Tunnel became operational in 1987 and initial performance testing was published in 1993 by Zell [4]. In this tunnel calibration experiment, area surveys were completed within the full-scale facility mapping local turbulence over 75% of the test section area. Original results are found in Ref. [4], figures 51-54. Results from this analysis determined that atmospheric winds (again, uncontrolled) had negligible effects on flow quality at test section speeds > 36 m/s (70 knots). Wind onset direction was not reported. Additionally, effects of wind on turbulence distributions could not be resolved. For a full description of the testing setup, instrumentation and analyzed parameters see Ref. [4].

The primary goal of this paper is to provide new insight into the performance of the as-built 80x120 inlet for controlled ambient atmospheric wind conditions for both wind velocity and onset wind direction. Specific areas of research using the test section turbulence levels as performance flow quality metrics were:

- Tunnel flow quality as a function of tunnel airspeed in quiescent winds (zero ambient atmospheric airspeed).
- Tunnel flow quality as a function of ambient wind speed for winds aligned with the center test section.
- Tunnel flow quality as a function of onset wind direction (± 90 deg) from center-line at fixed ambient wind velocity and varying tunnel-airspeed.
- The ability to create additional wind tunnel test section turbulence and boundary layer profile to simulate the earth's atmospheric boundary layer for future test programs (buildings and wind turbine testing).

This was performed by measuring the turbulence levels as they are affected by atmospheric wind velocities, internal test section airspeed, wind onset yaw angle, and obstruction to inlet mouth. These measurements were collected in an area 75% of the test section plane in the 1/50th-scale model of the 80x120 tunnel. The 1/50th-scale model used in testing within the full-scale wind tunnel is shown in Fig. 6.

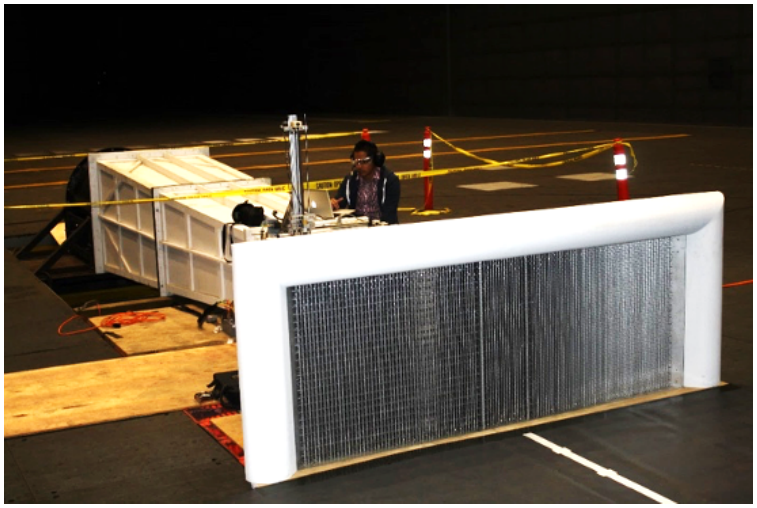

Fig. 6   1/50th-scale model of 80- by 120-Foot wind tunnel.

III. Test Setup

Testing was done in the full-scale 80- by 120-Foot Wind Tunnel with the 1/50th-scale model of said tunnel outfitted with a single fan, 400-hp electric motor drive system. Ambient atmospheric winds were simulated using a six fan array drive system 22.6 meters upstream of the model inlet. The model was mounted on the turntable within the full-scale test section. The turntable was used to simulate changes in onset ambient wind direction in a range of +90 deg to –90 deg. The A Series 100 Cobra Probe is a multi-hole pressure probe designed to provide three dynamic orthogonal directional components of velocity and turbulence measurements. The probe is capable of ± 45 deg angle measurements, and provided the aerodynamic data used in this analysis. This probe was mounted within the model test section and was used to collect 25 point area surveys equaling 75% of the test section's area along the lateral and vertical directions. The testing grid is shown in Fig. 7. For a full description of testing setup, instrumentation and procedures see Ref. [5].

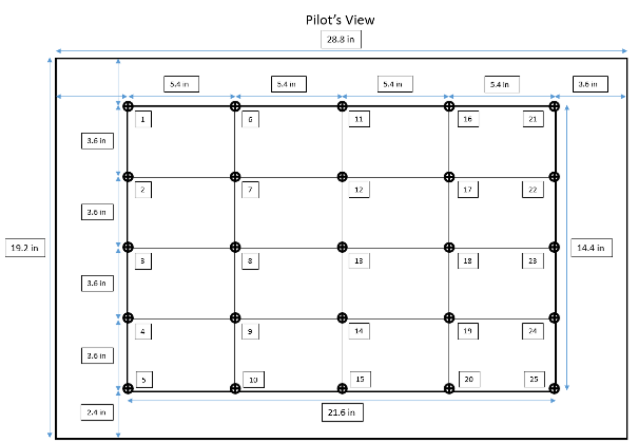

Fig. 7   Cobra probe survey locations. 25 grid point survey; pilot's view.

Testing configurations for the wind tunnel were determined by varying yaw angle (Ψ), ambient wind speed (V_{wind}) and test section speed (V_{ts}) shown in Table 1.

Limitations in ambient winds were due to maximum mass flow rates of the six electric blower fans. Yaw angle limitations were both setup limitations and testing choice, anything outside the ± 90 deg of the forward face on the inlet would not have been geometrically representative of the full-scale tunnel structure. Lastly, for intentional blockage of the inlet, triangular cardboard cutouts were used to obstruct the flow into the tunnel. Figure 8 shows the two sizes of spires used.

Table 1 Testing Configurations

Parameters	Possible Settings
Ψ	-90 ° to 90 ° in increments of 30 °
V_{wind}	Max Wind = 3.5 m/s at inlet or No Wind
V_{ts}	5, 7.5, 10, 15, 20, 30, 40 and 50 m/s

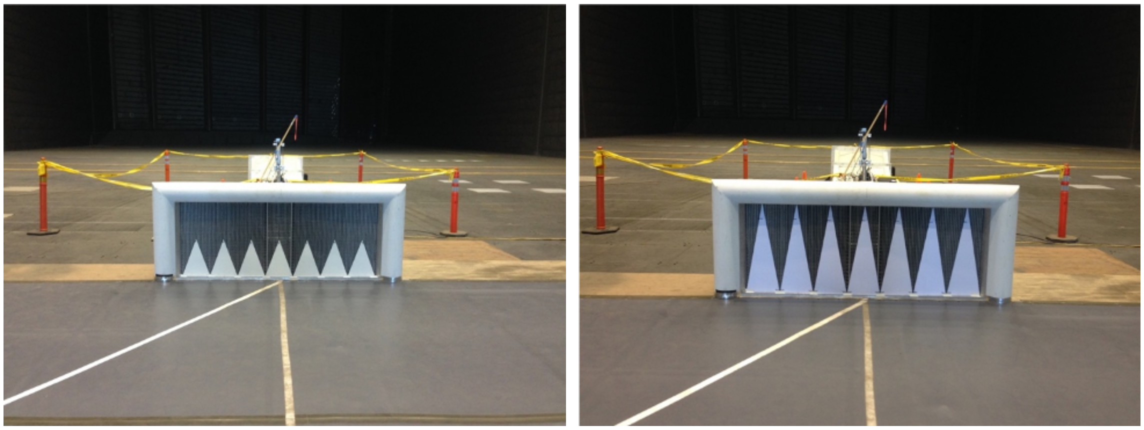

Fig. 8 Small spires (left); large spires (right).

IV. Results

Representative results from testing are shown and discussed in the following section; comparison to historical data will also be included.

A. Center-Line Turbulence Levels at 0 Deg Onset Winds (Center-Line Winds)

Measurements of each component of relative turbulence intensity at the test section center-line (I_{uu}, I_{vv}, and I_{ww}) are presented in Fig. 9 in addition to the average turbulence intensity (I_{uvw}) as a function of V_{wind} / V_{ts} for turntable yaw angle (Ψ) of 0 deg. In each subplot of Fig. 9, a single color represents a specific velocity in the test section, V_{ts}, as V_{wind} is varied from 0 to 50%, 75%, and finally 100% max V_{wind}. Maximum V_{wind} is approximately 3.5 m/s at the inlet for maximum output from the six-blower array. A linear least-squares curve fit has been applied to each data set at constant test section velocity. Each linear least-squares curve fit is close to horizontal, indicating that the center-line turbulence intensity is, in general, insensitive to atmospheric wind in both magnitude and direction.

For V_{wind} = 0, the Y-axis shows the dependence of center-line turbulence on V_{ts} alone. It can be seen that test section turbulence increases as the test section velocity decreases for V_{wind} = 0, and has greater significance than the dependence solely on V_{wind}. This is because the test section center-line turbulence has shown to be almost independent of V_{wind} (curve fit lines are nearing horizontal in most cases).

Measurements of test section center-line turbulence are presented for 0 < V_{wind} < 3.5 m/s (8 mph) and 5 m/s < V_{ts} < 50 m/s. For test section velocities of 5 m/s, the optimal curve fit may not be linear, this is to be expected. For a test section velocity of 5 m/s, and the inlet contraction ratio of 5, an induced velocity at the inlet plane of only 1 m/s (3.28 ft/sec, 197 fpm) is implied. Variability in recirculation inside the NFAC 80x120 test section becomes important as the recirculation velocity approaches the induced velocity at the inlet plane.

Figure 9 should be compared with equivalent data from the full-scale facility presented earlier in Fig. 5. The full-scale facility showed that the test section center-line turbulence intensities are independent of external wind for V_{ts} > 46.3 m/s (90 knots). The same is certainly indicated at model scale. Model-scale measurements further indicate that test section center-line turbulence is independent of atmospheric wind for test section velocities of 10 m/s or greater. Model-scale measurements also indicate that the primary determinant of test section center-line turbulence is the test section velocity.

Data presented in Fig. 9 are limited to the maximum wind speed at the inlet available from the six-blower array running at maximum speed, namely 3.5 m/s. However, each linear least-squares curve fit in Fig. 9 is sufficient so that extrapolation to an absolute maximum expected wind speed of 10 m/s (20 mph) is believed to be a valid operation in order to extend the correlation to the full-scale operational envelope. This operation only appears to be unreliable for V_{ts} = 5 m/s, but a test section velocity of 5 m/s (≈ 10 knots) is an unusually low test condition for the full-scale facility. Figure 9 shows test section center-line turbulence for Ψ = 0 degrees with each linear curve fit extrapolated to V_{wind} = 20 mph (the maximum ambient wind speed anticipated at the full-scale 80x120 inlet). Data from two separate runs (indicated by triangles and circles) are included in each subplot of Fig. 9 to demonstrate measurement repeatability.

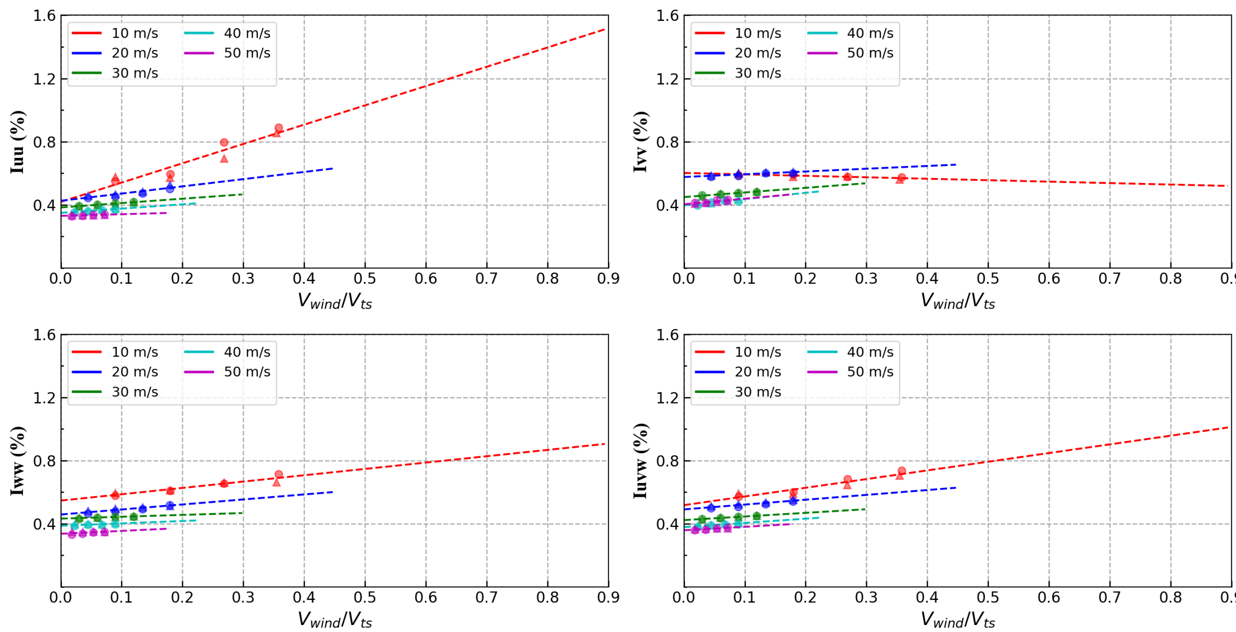

Fig. 9 Test section center-line turbulence for Ψ = 0 deg.

B. Wind Tolerances

Experimental results were acquired for all possible configurations with possible settings outlined in Table 1. Turbulence measurements were taken at the center point of the wind tunnel test section. The test section center is where all aircraft will be located during aerodynamic testing and therefore provides the most significant indication with regards to tunnel air flow quality. Due to limitations in the fan drive system simulating ambient winds, maximum wind speed was approximated to be 3.5 m/s at the inlet. The methodology for turbulence levels at greater ambient wind speeds was developed in this study using the extrapolated curve fits calculated for the yaw angle (Ψ) tested and then linearly interpolated between yaw angles (see discussion in previous section for 0 deg yaw case curve fitting). Figure 10 shows the wind tolerances for each test section velocity with the following criteria: Acceptable – $I_{uu} \leq 0.5\%$, $I_{vv} \leq 0.6\%$, Test Dependent – $0.5\% < I_{uu,vv} \leq 1\%$, Marginal $I_{uu,vv} > 1\%$, for atmospheric wind speeds from 0 to 10 m/sec (20 knots) and 180 deg of onset direction.

Original wind tolerances were determined theoretically by Eckert and Mort in 1979 [2], though testing of the inlet configuration as-built was not performed. Eckert and Mort did not state the definitions of Test Dependent and Marginal limits and therefore assumptions were made as to what they might have been. Facility flow quality criteria were then determined based on design specifications and experimental data provided by Ref. [3]. In Ref. 3 the testing was performed with a 1/15th-scale model of the tunnel as-built, but did not include variations in wind directions since the experiment used existing ambient wind onset directions. Zell's full-scale testing did come to the conclusion for test section speeds greater than 46.3 m/s that atmospheric winds had negligible effect of flow quality [4], though again wind direction was uncontrolled and only limited onset directions were experienced. In the current study, 180 degrees of ambient onset wind direction was evaluated together with a range of wind tunnel test section speeds.

It has been determined in this study that the wind tunnel can be operated at acceptable turbulence levels for tunnel test section airspeed ≥ 30 m/s. As the test section airspeed decreases, the effects of prevailing winds on the flow quality

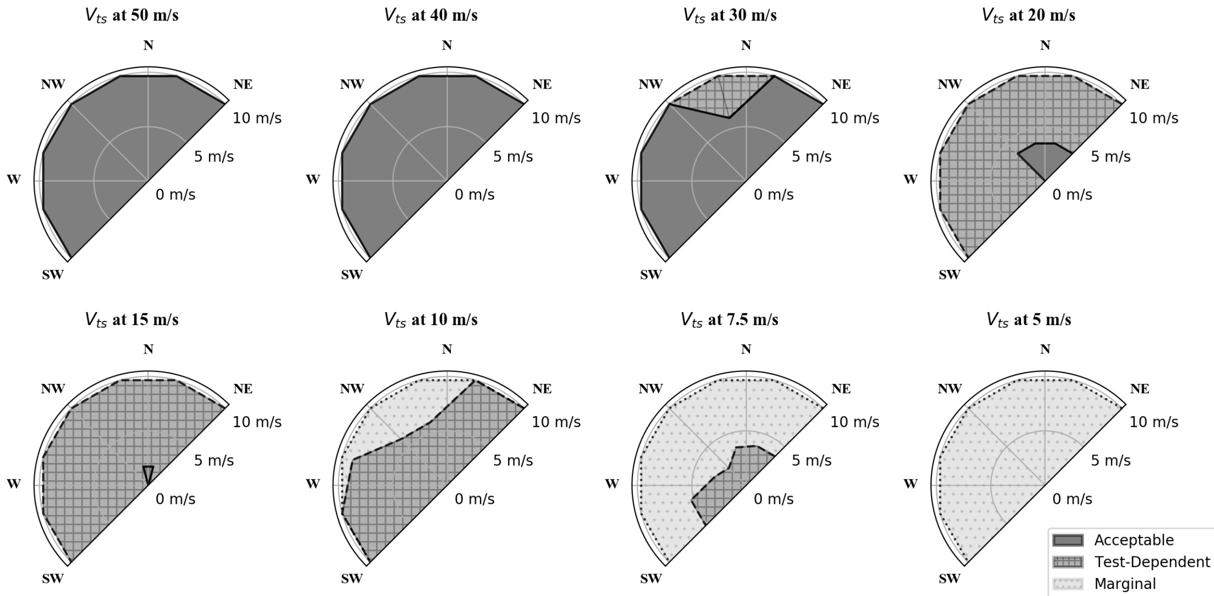

Fig. 10 Wind tolerances as a function of test section airspeed (V_{ts}), wind onset angle (Ψ), and ambient atmospheric wind speed (V_{wind}).

within the test section increase. Once the test section airspeed is below 10 m/s, the largest variation in turbulence is seen in the test section and flow quality fails to meet previously determined flow quality specifications for satisfactory tunnel operation for aerodynamic testing.

Further analysis was performed within the test section of the tunnel and confirmed that the direction of ambient wind had a minimum effect on the function of the tunnel to provide acceptable steady state conditions above a certain V_{ts}. Figure 11 shows the effect of onset ambient flow direction impacting the average relative turbulence of all three orthogonal directions taken at the center point of the test section. Substantial increases in turbulence levels were measured for low wind tunnel test section airspeeds. Additionally, the highest turbulence levels at low wind tunnel test section airspeeds were measured when the onset wind direction was aligned with the wind tunnel center-line.

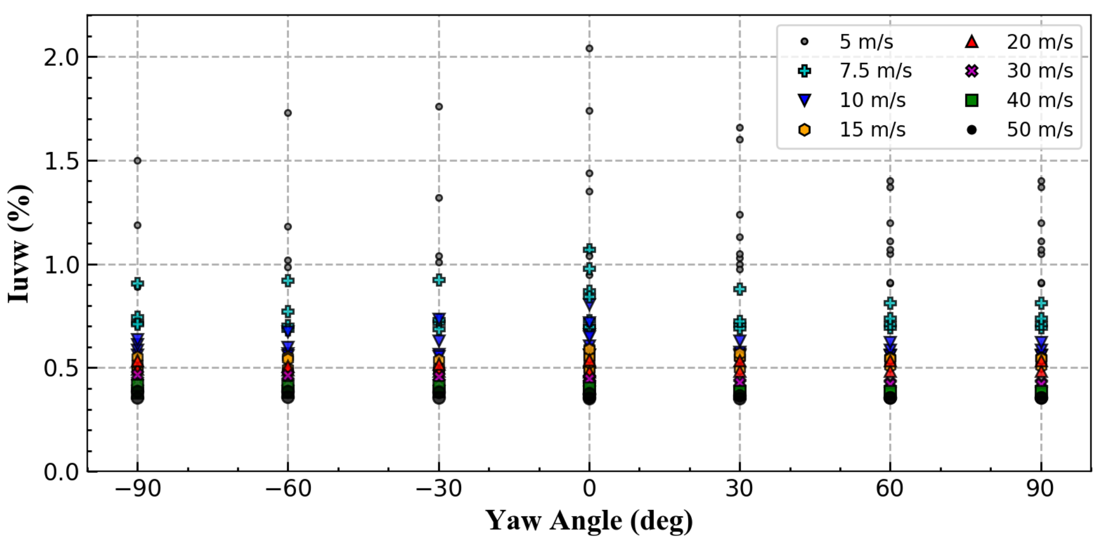

Fig. 11 I_{uvw} as a function of yaw angle Ψ, at max ambient wind speed (3.5 m/s) for all tested V_{ts} speeds.

Relative overall turbulence (I_{uvw}) value and variation increases as V_{ts} decreases, though no significant effect is seen due to the direction of ambient wind direction. This clearly establishes a large range of acceptable atmospheric conditions in which the tunnel can be operated while producing accurate and usable aerodynamic data at tunnel airspeeds above 10 m/s.

C. Turbulence in the Test Section

Area surveys were completed over 75% of the vertical/lateral plane of the test section using the most significant configurations for greatest/least effect on tunnel operation. Of the data collected, ortho-directional wind velocity (U, V and W) were analyzed along with their corresponding turbulence measurements (I_{uu}, I_{vv} and I_{ww}). This was to determine how the turbulence is distributed throughout the test section and determine what features, if any, caused local hot spots. As stated earlier, the U-direction dominates within the test section and therefore the analysis is focused on the I_{uu} turbulence components. Figure 12 shows the turbulence map for the configuration at 0° Ψ, V_{ts} = 50 m/s with no wind and max wind conditions.

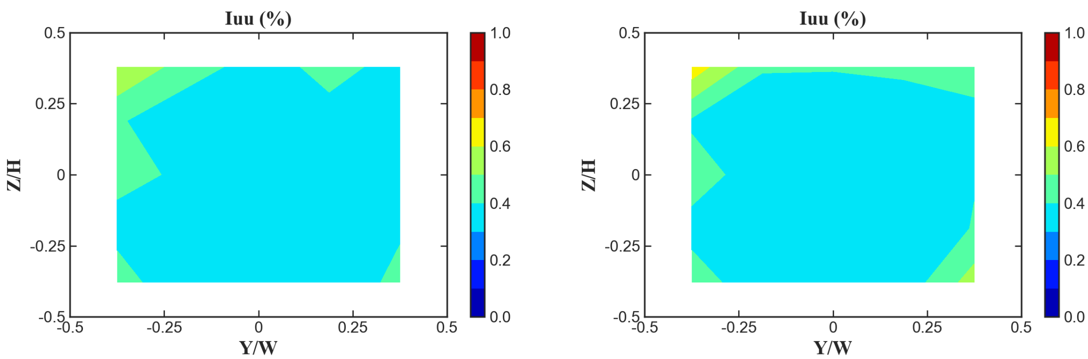

Fig. 12 No wind condition (V_{wind} = 0, left) and maximum wind condition (V_{wind} = 3.5 m/s, right) at 0° Ψ and V_{ts} = 50 m/s.

Based on the design specifications, the 1/50th-scale model demonstrates what was seen during full-scale testing performed by Zell [4], that is, the $I_{uu} \leq 0.5\%$ on the center-line of the test section. The model data also shows that the atmospheric winds have a minimal effect on the uniformity of the turbulence seen in the test section. Figure 13 shows the turbulence map for the configuration at 0° Ψ, V_{ts} = 25 m/s with no wind and max wind (V_{wind} = 3.5 m/s) conditions. Again, the uniform nature of the turbulence is still unaffected; although the turbulence has increased, it remains within the design specifications.

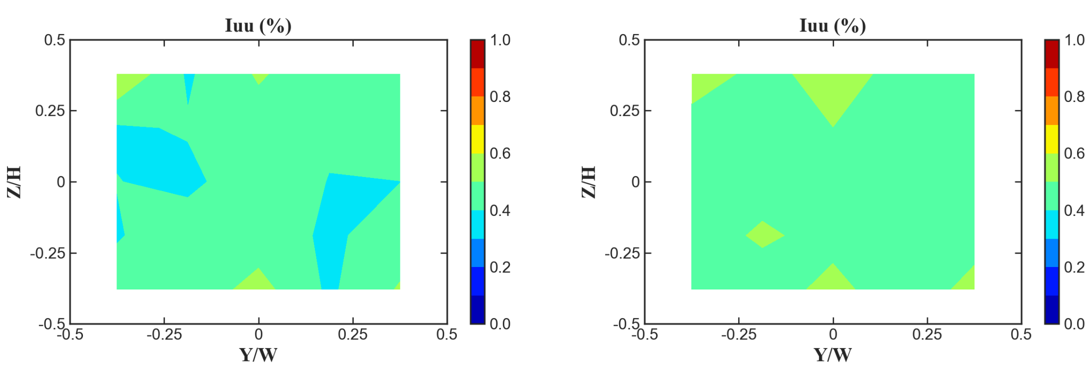

Fig. 13 No wind condition (V_{wind} = 0, left) and maximum wind condition (V_{wind} = 3.5 m/s, right) at 0° Ψ, V_{ts} = 25 m/s.

Figure 14 shows the turbulence map for the configuration at 0° Ψ, V_{ts} = 10 m/s with no wind and max wind (V_{wind} = 3.5 m/s) conditions.

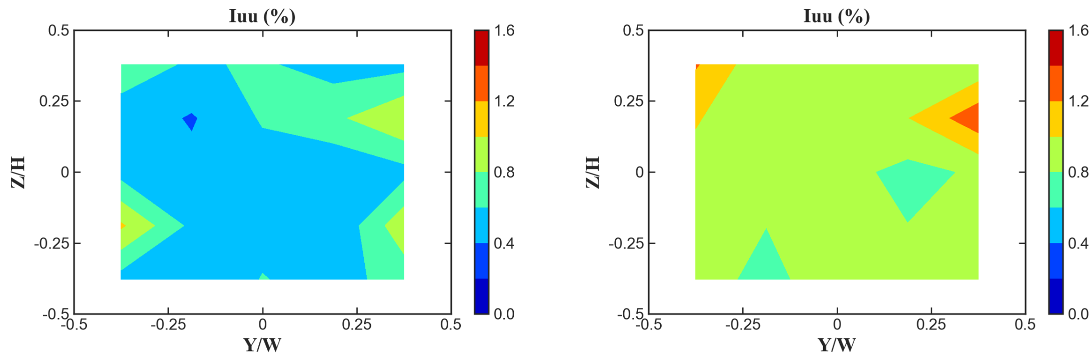

Fig. 14 No wind condition (V_{wind} = 0, left) and maximum wind condition (V_{wind} = 3.5 m/s, right) at 0° Ψ, V_{ts} = 10 m/s.

Here, an increase in turbulence is seen that exceeds the historically accepted limits. Overall turbulence within the test section is relatively uniform, regardless of test section speed, and as the tunnel speed decreases the turbulence will increase.

D. Spires

The goal of intentionally blocking the flow into the inlet was to generate higher levels of free stream turbulence in the wind tunnel test section while also establishing a more representative earth boundary layer profile. Of the two spire configurations tested (Fig. 6), the small spires showed minimal effect on the flow quality within the tunnel test section and therefore will not be shown here (for complete graphs see Ref. [5]). The large spires covered ≈ 50% of the inlet mouth and showed the desired effect on airflow quality within the test section; Fig. 15 shows the area survey of the turbulence flow for V_{ts} = 10 m/s. For this tunnel operating configuration, the non-uniformity of the test section flow quality is a direct result of the large spires installation; the atmospheric wind has little effect on the turbulence intensity distribution over the majority of the survey area.

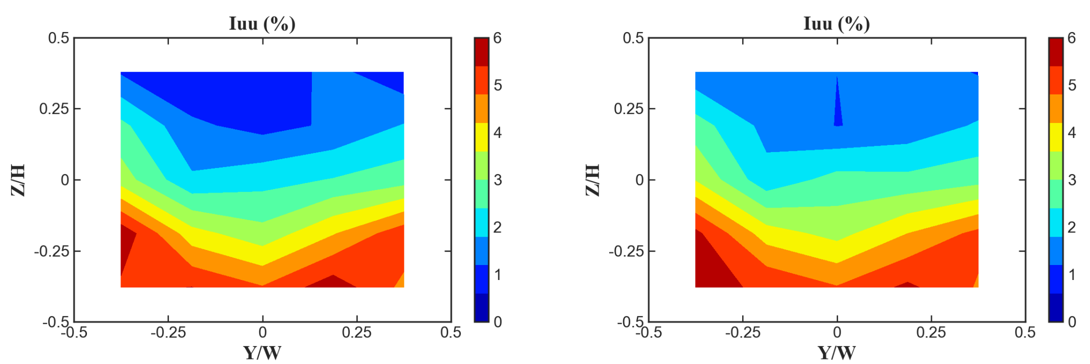

Fig. 15 No wind condition (V_{wind} = 0, left) and maximum wind condition (V_{wind} = 3.5 m/s, right) at 0° Ψ, V_{ts} = 10 m/s with large spires installed.

With the introduction of the large spires a vertical gradient in turbulence is seen within the survey plane with the greatest levels seen near the floor of the test section. At low wind tunnel test section airspeed, the large spires obstruction at the inlet can achieve up to a maximum twelve-fold increase in turbulence (0.5% to 6% I_{uu} at V_{ts} = 10 m/s) within the survey plane.

E. Summary of Results

In this study, it was determined that the performance of the inlet on flow quality has greater operational ranges then what was previously thought. First, the notion that wind direction has a great effect on the flow quality is proven to be inaccurate in this experimental study. The inlet is not particularly sensitive to onset atmospheric wind direction from ± 90 deg from tunnel center-line. Second, the greatest effect on flow quality and turbulence level is the speed at which the tunnel is operated at. The inlet performance with onset wind speed of 3.5 m/sec does not meet the tunnel design specification for 0.5% center-line turbulence for $V_{ts} < 20$ m/s. Though for $V_{ts} \geq 20$ m/s, the tunnel design specification for 0.5% center-line turbulence or less is met.

Lastly, high turbulence levels can be generated within a wind tunnel provided obstructions are placed in advantageous locations upstream of the air flow (in this case at the inlet). Here, the greatest level of turbulence achieved is 2.5-3.5% on the center-line of the tunnel operated at $V_{ts} < 10$ m/s.

V. Concluding Remarks

An inlet performance test of the NFAC 1/50th-scale 80- by 120- Foot Wind Tunnel model was conducted. Turbulence level surveys within a 75% vertical area plane at the center of test section were measured as a function of tunnel airspeed, atmospheric wind, and atmospheric wind onset direction relative to the tunnel center-line.

Flow quality results for the 1/50th-scale model determined acceptable agreement with historical conclusions, though in certain regards increased the tolerance of operational limits for the tunnel. Conclusions based on original testing put maximum turbulence levels at the center-line to be $I_{uu} \approx 0.4\%$ and $I_{vv} \approx 0.6\%$ with a test section velocity > 46.3 m/s for ambient winds < 7.7 m/s. Theoretical assumptions also limited acceptable wind directions (Fig. 2). Results produced here determined that for $V_{ts} \geq 20$ m/s ambient wind direction has a negligible effect on flow quality inside the tunnel and turbulence levels remain within design specifications.

Acknowledgements

We would like to thank the U.S. Air Force Arnold Engineering Development Complex for providing test support and the National Full-Scale Aerodynamics Complex 80- by 120-Foot Wind Tunnel test section for the necessary testing. Further, we would like to thank the Aeromechanic Interns for their assistance in building the models and acquiring the test data; Barry Porter and Dr. Alan Wadcock for their mentorship throughout all testing; lastly, Dr. William Warmbrodt for all the continued support and guidance through this project.

References

[1] Mort, K. W., Eckert, W. T., and Kelly, M. W., "The Steady-State Flow Quality in a Model of a Non-Return Wind Tunnel," *Canadian Aeronautics and Space Institute*, Vol. 18, No. 9, 1972, pp. 285, 289. (Also NASA TM X-62170, 1972).

[2] Eckert, W. T., and Mort, K. W., "Earth Winds, Flow Quality, and the Minimum-Protection Inlet Treatment for the NASA Ames 80- by 120-Foot Wind Tunnel Non-Return Circuit," 1979. NASA/TM-1979-78600.

[3] van Aken, J. M., Ross, J. C., and Zell, P. T., "Inlet Development for the NFAC 80- by 120-Foot Indraft Wind Tunnel," *AIAA 6th Applied Aerodynamics Conference*, 1988. Williamsburg, Virginia.

[4] Zell, P. T., "Performance and Test Section Flow Characteristics of the National Full-Scale Aerodynamics Complex 80- by 120-Foot Wind Tunnel," 1993. NASA/TM-1993-103920.

[5] Wadcock, A. J., Porter, B. J., Wagner, L. N., and Dromiack, H. T., "Effect of Atmospheric Wind and Upstream Buildings on the Flow Quality in the Test Section of the 80- by 120-Foot Wind Tunnel," 2020. NASA/CR-20205000668.