Upwind Buildings Effects on Test Section Performance of the NFAC 80- by 120-Foot Wind Tunnel

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

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

In 2013, a new development began that would put multi-story buildings within the exclusion zone of the 80- by 120- Foot Wind Tunnel (80x120) inlet that exceeded the then existing building height restriction. This raised questions concerning whether the tunnel could operate within the acceptable turbulence limits of $\leq$ 0.5% in the axial direction over 75% area in the wind tunnel test section. The goal of this testing was to determine the validity of this hypothesis. Testing was performed using the 1/50th-scale model of the 80- by 120-Foot Wind Tunnel within the full-scale facility test section to characterize the model's test section turbulence levels as a function of wind direction with the presence of the upwind buildings that are currently being constructed. This paper reports the first testing performed to date on the 80x120 inlet as-built under controlled test conditions for wind magnitude and wind onset direction for a variety of buildings in the inlet external flow field, including no buildings (the control case). This testing determined that, at rated operational conditions the upwind blockages caused no increase in turbulence intensity levels measured in the test section and, in some limited cases, caused the turbulence levels to decrease. Lastly, looking at generic rectangular blockages showed that, to have a discernible effect on test section turbulence levels, scaled 100-ft tall blockages need to be within 600 ft of the existing inlet.

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
MVC	=	Mountain View Complex
U	=	axial velocity (m/s)
V	=	lateral velocity (m/s)
W	=	vertical velocity (m/s)
V_{wind}	=	ambient wind velocity
V_{ts}	=	test section velocity
Ψ	=	turntable yaw angle

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

NASA Ames Research Center is home to the U.S. Air Force-operated National Full-Scale Aerodynamics Complex (NFAC) 80- by 120-Foot Wind Tunnel (80x120), the largest wind tunnel in the world. The tunnel is an open circuit tunnel and utilizes a large inlet with a 5:1 contraction ratio. Open circuit tunnels are affected by local atmospheric conditions; because of this the inlet was constructed to minimize external atmospheric winds, designed for a free stream turbulence level of ≤ 0.5% in the axial direction. This was done using splayed vertical vanes coupled with horizontal splitter plates to straighten out oncoming atmospheric winds. Mesh screens were installed on the inlet; the trailing edge was outfitted with an aerodynamic treatment screen for reducing turbulence caused by the vertical vanes and horizontal splitter plates and the leading edge had a screen installed for keeping birds out of the facility. These treatments worked well to mitigate external turbulence for many years [1]. Figure 1 shows an aerial view of the NFAC and the inlet.

Fig. 1 Aerial view of NFAC and the 80- by 120-Foot Wind Tunnel inlet.

After the tunnel's construction in 1987, initial performance testing completed within the full-scale 80x120 and published in 1993 by Zell, concluded that the tunnel was built to align with local prevailing winds [2]. Figure 2 shows that from the FLOCAL testing done that the majority of winds come from the northwest between 0 and 10 m/s (20 knots).

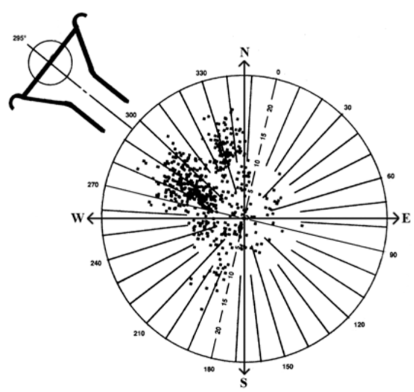

Fig. 2 Wind rose for 80x120 wind tunnel inlet (adjusted from Zell, Ref. 2, Fig. 56).

During this time, a large area upstream of the inlet, in this higher winds zone, was declared a building exclusion zone; there was concern that any new buildings could potentially impact turbulence levels within the test section. In 2004, this was amended to a height restriction within the zone. However, in 2013, a section of the exclusion zone, between the inlet and the prevailing winds, was leased by NASA to Planetary Ventures, a subsidiary of Google (now Alphabet) for new office development without an understanding of the impact on wind tunnel operations and tunnel flow quality, particularly under windy conditions. For the purposes of this paper, the three office building complex is referred to as the Googleplex. Figure 3 shows a schematic of the buildings upstream of the inlet, prior to Google's new construction, along with their position relative to the inlet's centerline and their names. Figure 4 shows a live image of the building exclusion zone, including these existing buildings and the future Googleplex site.

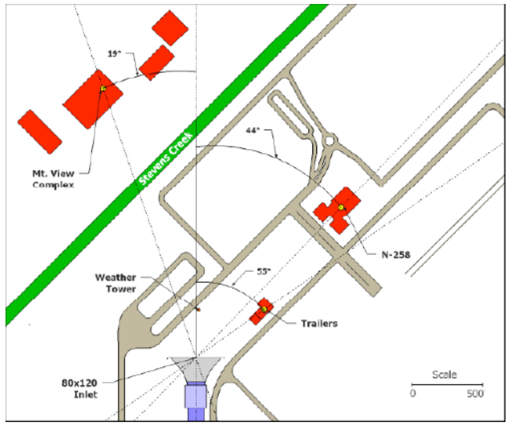

Fig. 3 Map of existing buildings, prior to 2019, with their location and name.

Fig. 4 Location of new Googleplex Development (Bayview Concept, Ref. [3]).

Two phases of initial testing were performed in 2013 and 2014 to examine the effects of upwind blockages based on the expected shape and location of these new buildings. Early designs for the Googleplex showed several simple, square buildings, similar to the existing buildings around. Testing was performed at 1/50th-scale, using a model of the 80x120. Phase I testing, reported in Ref. [4], utilized the 1/50th-scale model without an appropriate inlet treatment, so the results of Phase II were used as the main guidance for future tests. Results from these initial tests determined that for the generic rectangular blockages 1-ft tall (50-ft tall full scale) to generate a discernible effect on turbulence levels within the test section, they would need to be within 8 ft (400 ft at full scale) of the inlet [5]. This phase of testing did not include atmospheric wind studies. After these initial tests reported in Ref. [5], were completed, a design change occurred in the Googleplex buildings. The new design featured three larger buildings, each with a unique, scalloped roof, that added a level of uncertainty to the expected effects. Figure 5 shows a rendered model of the new Googleplex campus buildings currently under construction.

Fig. 5 Preliminary design of the Googleplex Development (Bayview Concept, Ref. [3]).

Because on this new design, new tests were needed to ensure that the changed buildings would not negatively impact the turbulence levels in the tunnel. The new tests would be performed in the 80x120 wind tunnel test section, and utilize a similar experimental design as the previous tests. A variety of experiments, featuring different types of blockages and wind and turbulence studies were performed in this testing period, which spanned from Fall 2018 through Summer 2019. This paper will discuss the results of studies performed using the scaled building models of both the existing buildings and future Googleplex, as well as the effects of generic blockage in front of the inlet. Full details and the results of the entire test plan can be found in Ref. [6]; this paper will exclusively discuss the results of building and blockage on turbulence levels.

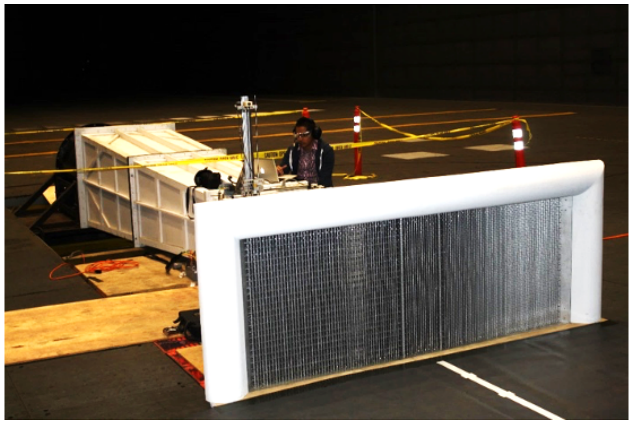

Fig. 6 1/50th-scale model of the 80- by 120-Foot Wind Tunnel.

III. Test Setup

Testing was completed within the full scale 80x120 using the 1/50th-scale model designed with a drive system comprising a single 400 hp electric motor fan. Atmospheric winds were simulated using a 6-array fan blower assembly capable of simulated winds up to 7 knots (3.5 m/s) at the inlet. The 80x120 drive system was not available for use in this test, and the blower system had a variety of limitations (i.e., non-uniformity of flow and an outflow skew angle of approximately 5 deg). The generated wind also decayed as it travelled away from the blower system toward the inlet, a characteristic that real atmospheric wind does not have. This is a limitation of the wind on testing data with the experimental test setup.

The existing buildings located near the inlet were constructed out of poster board during the 2014 test. These buildings can be seen in red in Figure 3. The new Googleplex buildings, due to their highly complex roof geometry, were modelled as 2D silhouettes of the exposed frontal area when the onset wind direction was directed through the center of the largest building to the inlet center. This corresponds to a turntable yaw angle (Ψ) of -29 degrees. Atmospheric onset wind direction was controlled by using the 80x120 turntable on which the model wind tunnel was mounted. An image of the Googleplex building silhouettes can be seen in Figure 7. The fan drive system and data collection was controlled from the model prep area to eliminate any additional blockage created by drive system operation and data collection.

Two types of instrumentation were used in this study. In order to determine the onset wind speed, an Alnor probe survey was performed at the largest building's location and slightly upstream of the inlet. The Alnor probe provides airspeed measurements at a sampling rate of 1 Hz and measures total velocity magnitude. It was mounted on a cart and sampled for extended periods of time at a 30-ft wide, 6-ft tall plane at each location. By averaging the timed results, the velocity field and average wind speed at each position could be determined.

A 100 Series Cobra probe was used within the model test section, mounted on a remotely controlled 2D traverse. The probe provides three ortho-directional components of wind velocity (U, V, W) with corresponding turbulence intensity (I_{uu}, I_{vv}, I_{ww}), along with overall turbulence intensity (I_{uvw}) and angle measurements of ± 45 deg (yaw and pitch) at a sampling rate of 2 kHz. These directions can be seen in Figure 8.

The Cobra probe location was computer controlled and would autonomously move the probe between sampling locations and record data. Three Cobra probe movement patterns were used for data collection. The most common was area surveys, presented as contour plots in this paper, where the probe moved between 25 point surveys covering 75% of the cross sectional area of the test section, with the grid shown in Figure 9. In addition, some runs took points exclusively along the test section centerline, from Points 11 to 15. Finally, some runs only took centerpoint measurements, Point 12.

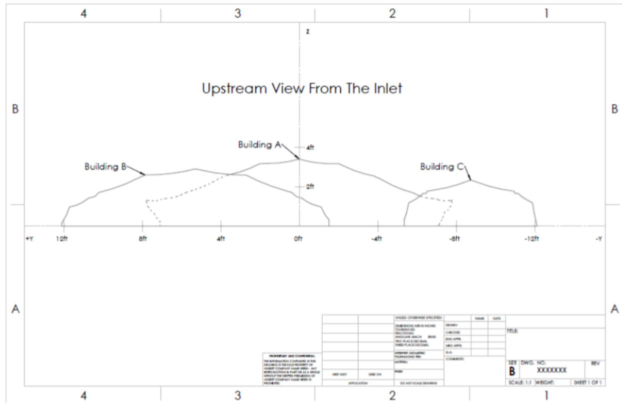

Fig. 7 Googleplex buildings silhouettes, viewed from centerline of largest building (Building A).

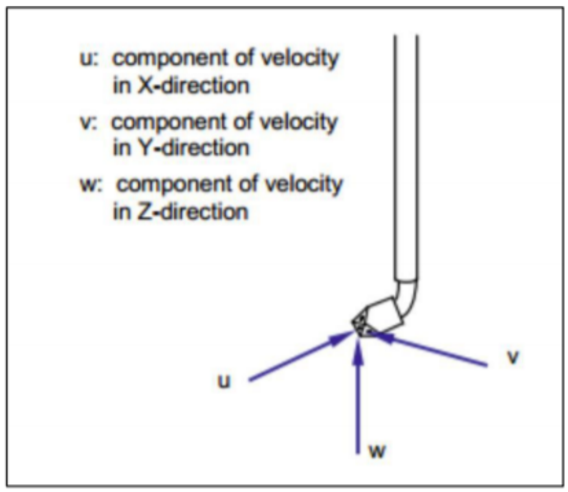

Fig. 8 Cobra probe directionality of velocity and turbulence components.

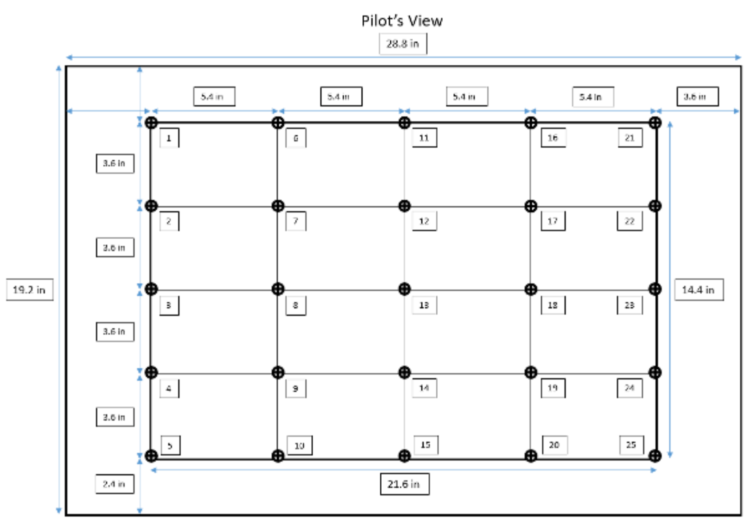

Fig. 9 Cobra probe survey grid, pilots view.

Wind and test section speed data was varied and recorded in a variety of ways. A majority of building studies were performed at the full (100 knots, or 51.4 m/s) or half (50 knots, or 25.7 m/s) test section speed with full onset wind speed. However, due to the low onset wind speed available and the occasional test involving lower test section speeds, studies were performed in order to categorize test section turbulence varying with the ratio of wind speed to test section speed, V_{wind}/V_{ts}. This method is discussed in detail in Ref. [7].

A. Building and Blockage Configurations

Testing configurations were determined by varying turntable yaw angle (Ψ), atmospheric wind speed (V_{wind}), test section speed (V_{ts}) and necessary buildings/blockages. These variables are shown in Table 1.

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
Buildings/blockages	MVC, Googleplex and NASA / 1x1x16 foot blocks

The building configurations tested in the external inlet inflow field include the Mountain View Complex (four existing building in the city of Mountain View beyond NASA Ames property), three 2D silhouette Googleplex buildings, and existing NASA buildings (Building N258 and trailers within the inlet inflow zone). Various combinations of these buildings were used, including existing buildings, only NASA buildings, only Googleplex buildings, and so on. This was done to determine the individual impact on test section turbulence from each group. Figure 10 shows the plan view for a run in which all buildings are present at Ψ = 0 deg and the setup within the tunnel.

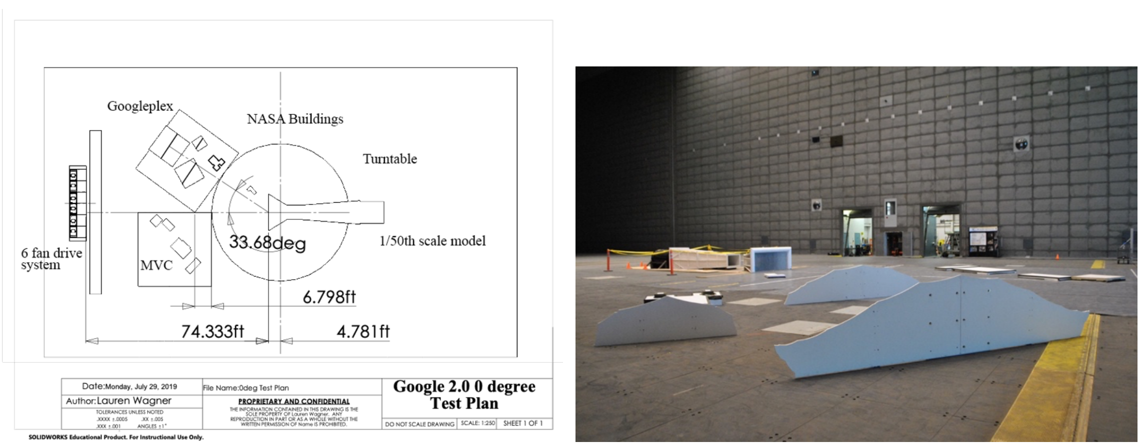

Fig. 10 Testing layout (left); Run within test section (right).

Generic blockages were used in the absence of buildings to determine how close a building would need to be in order to generate significant turbulence changes in the tunnel. These blockages consisted of four individual, 1x1 ft cross sectional area blocks 16-ft long. This allowed them to be stacked to examine the effects of various heights. Figure 11 shows the setup for a 4-ft wall blockage, 12 ft in front of the inlet. Two blockage arrangements in relation to the inlet centerline will be discussed in this paper. One involved centering the blockage on the centerline (shown on the left of Figure 11) and one involved placing the end of one block on the centerline (right of Figure 11).

Fig. 11 Generic 4-ft blockage @ 12 ft from inlet, centered (left), and generic 1-ft blockage @ 12 ft from inlet, end on centerline (right).

IV. Results

A. Effects of Atmospheric Winds and Googleplex Buildings

The effects of the Googleplex campus were widely unknown; it was determined that the worst case scenario would likely be strong winds directly over the Googleplex site being ingested into the tunnel. This was determined because of the unique shape of the buildings that make up the campus and their strategic location upstream of the inlet. Alnor probe surveys found maximum wind to be 7 knots at the inlet. This test configuration has a Ψ = -29 deg with all buildings present in the run at maximum wind. This places Building A, the largest building, perpendicular to onset winds. This test plan layout can be seen in Figure 12. A majority of building studies were performed at this angle. This angle was an attempt to account for an approximate deflection of 5 deg in the maximum outflow wind speed from the six-fan array and documented at the outset of the test program with the Alnor array sweeps at various downstream stations with no wind tunnel in place.

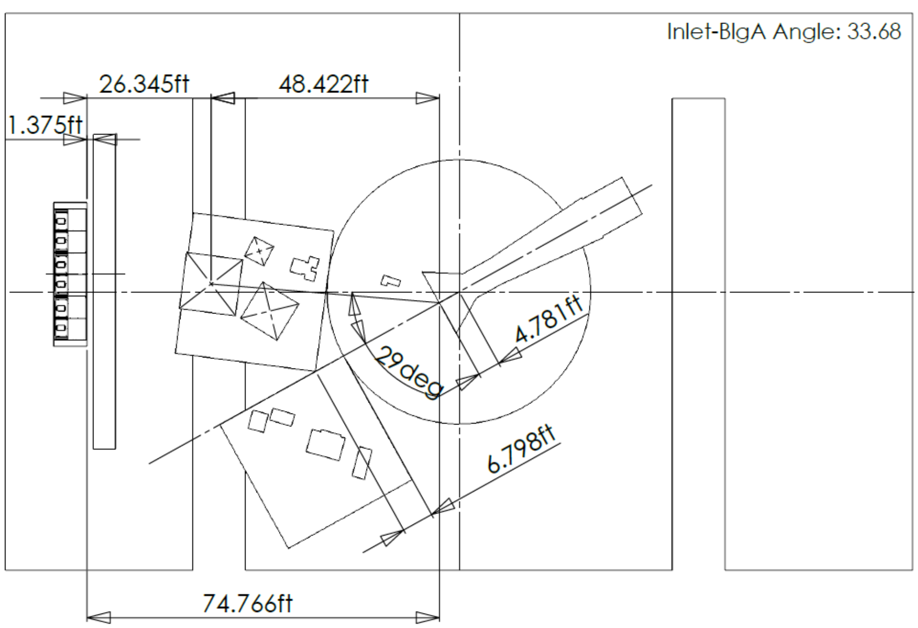

Fig. 12 -29-degree plan view. This configuration aligns the largest Googleplex building silhouette perpendicular to the onset winds.

Figures 13 through 16 shows contour plots of the velocity and turbulence measurements. These cases represent

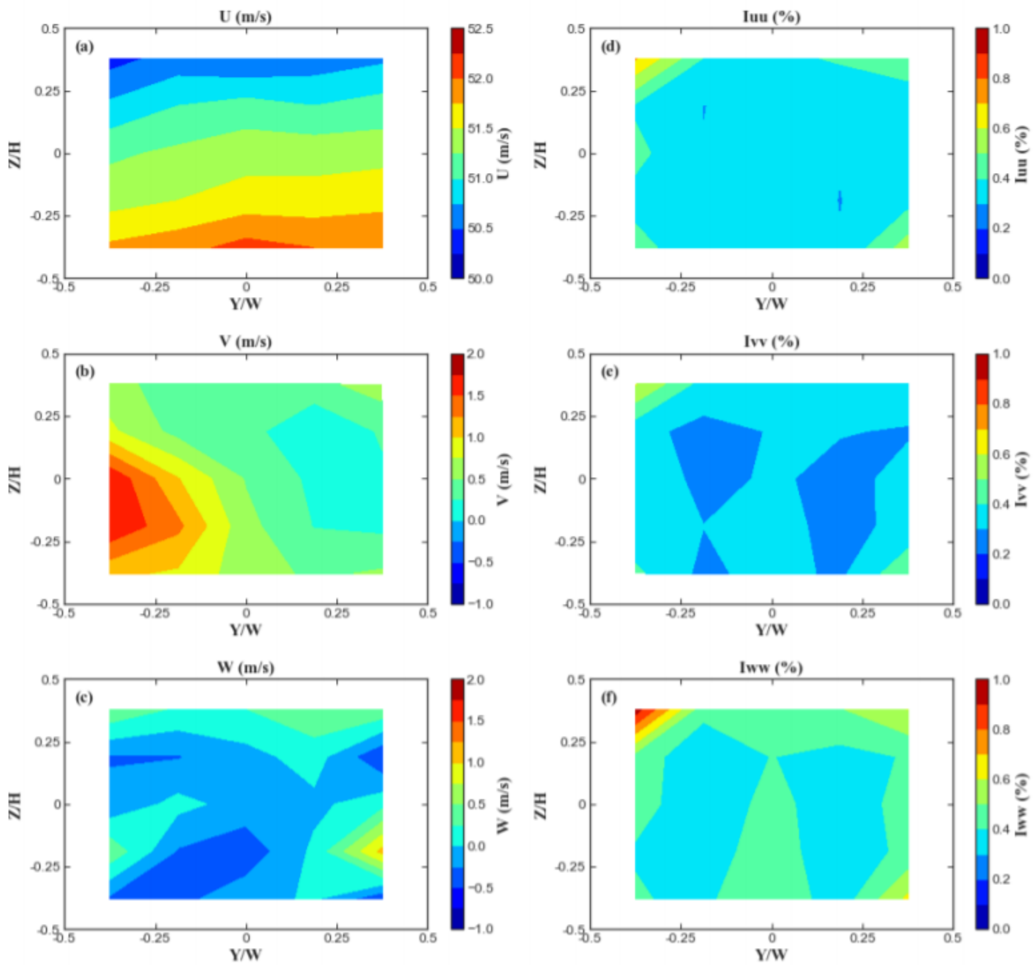

Fig. 13 Velocity and turbulence contour plots for Ψ = -29 deg, No Wind, Max Tunnel Speed, No Buildings case.

the extremes of testing. All runs were performed at a test section speed of 100 knots (51.4 m/s). For these cases, the optimal test section velocities would be near 100 knots in U, and near 0 knots in both V and W. Turbulence values in all direction should be below 0.5%.

First, the effects of wind on the tunnel without any buildings present is shown, in Figures 13 and 14. These plots represent the conditions prior to the Googleplex construction and provide a baseline for the previous tunnel operating conditions.

Overall, there are no significant changes in velocity or turbulence values due to the addition of wind at an onset angle of -29 deg. The turbulence values appear to experience a slight increase in I_{vv} and I_{ww} turbulence values, though these values are all close to or below the required threshold. Therefore, prior to building construction, wind did not drastically impact turbulence values in the tunnel at -29 deg onset angle. For the effect of wind onset angle with no buildings on test section turbulence, please see Ref. [7].

Next, the impact of the buildings with both no wind and wind conditions is shown in Figures 15 and 16. These conditions represent the future test section condition, following the completion of the Googleplex.

The no wind cases have almost identical plots, with nearly perfectly matching velocity and turbulence values. This indicates that the Googleplex is well out of range of the inlet's intake flow field, and is therefore not detectable in the test section in the absence of winds. When winds are present, there is a slight increase in the turbulence levels in I_{ww}; however, there are no significant changes in any other velocity or turbulence values. In addition, the turbulence values in I_{ww} are still below the 0.5% limit. Overall, this indicates that the Googleplex does not significantly impact the test section turbulence values for what is considered to be the worse case onset wind angle.

For ease of viewing, the U velocity and I_{uu} turbulence results from the no wind no buildings case, or baseline case,

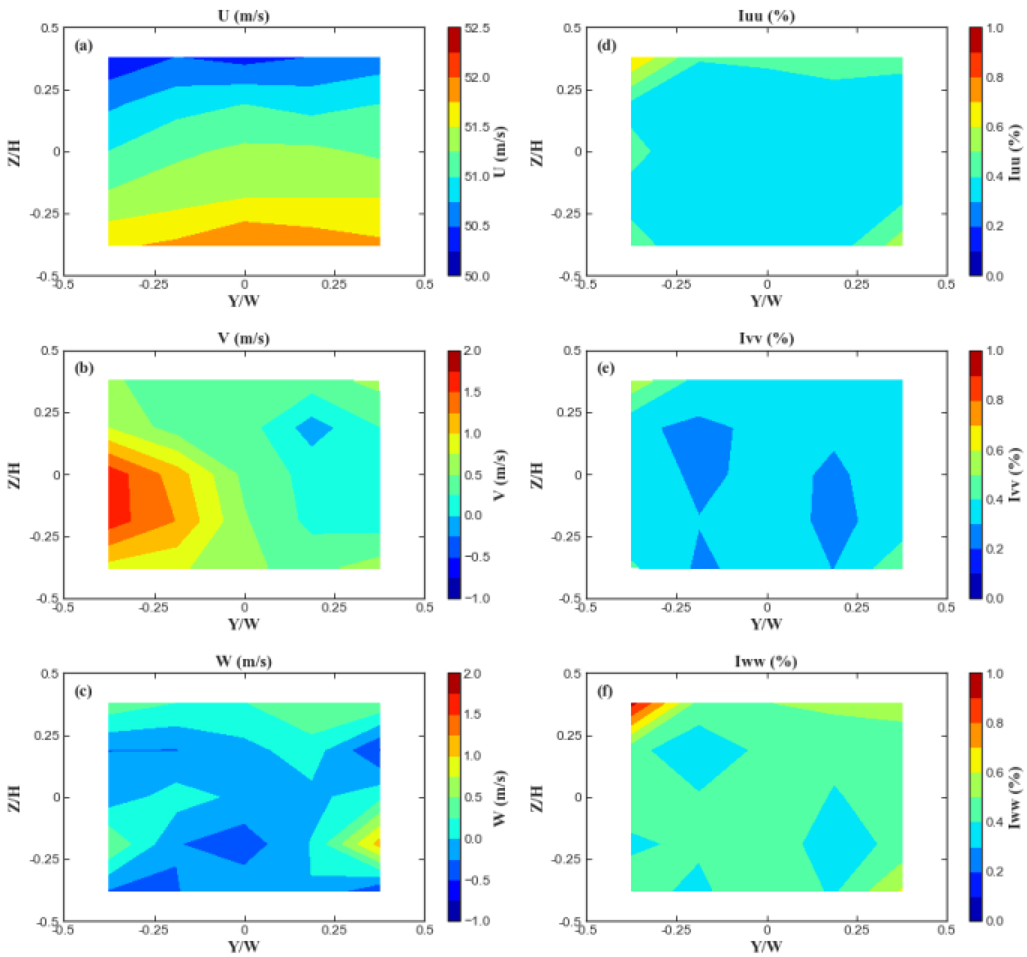

Fig. 14 Velocity and turbulence contour plots for Ψ = -29 deg, Max Wind, Max Tunnel Speed, No Buildings case.

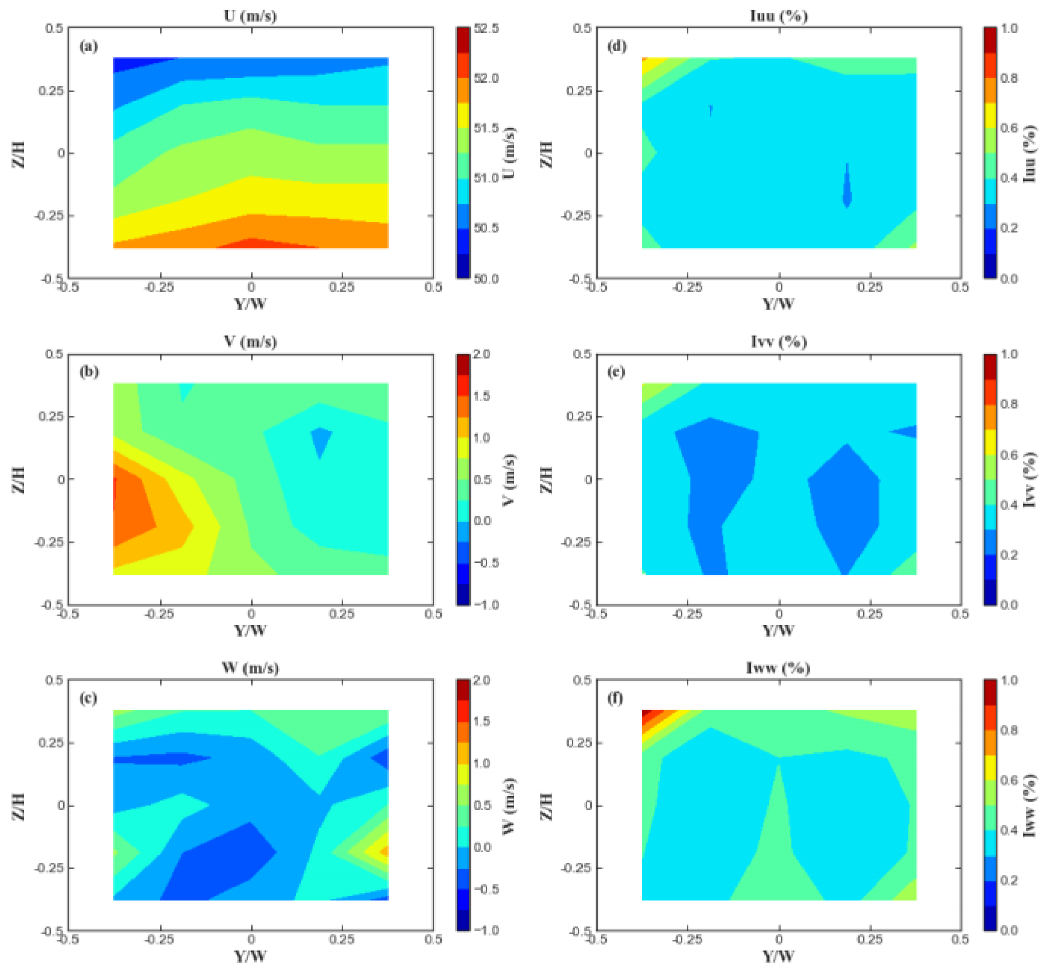

Fig. 15 Velocity and turbulence contour plots for Ψ = -29 deg, No Wind, Max Tunnel Speed, All Buildings case.

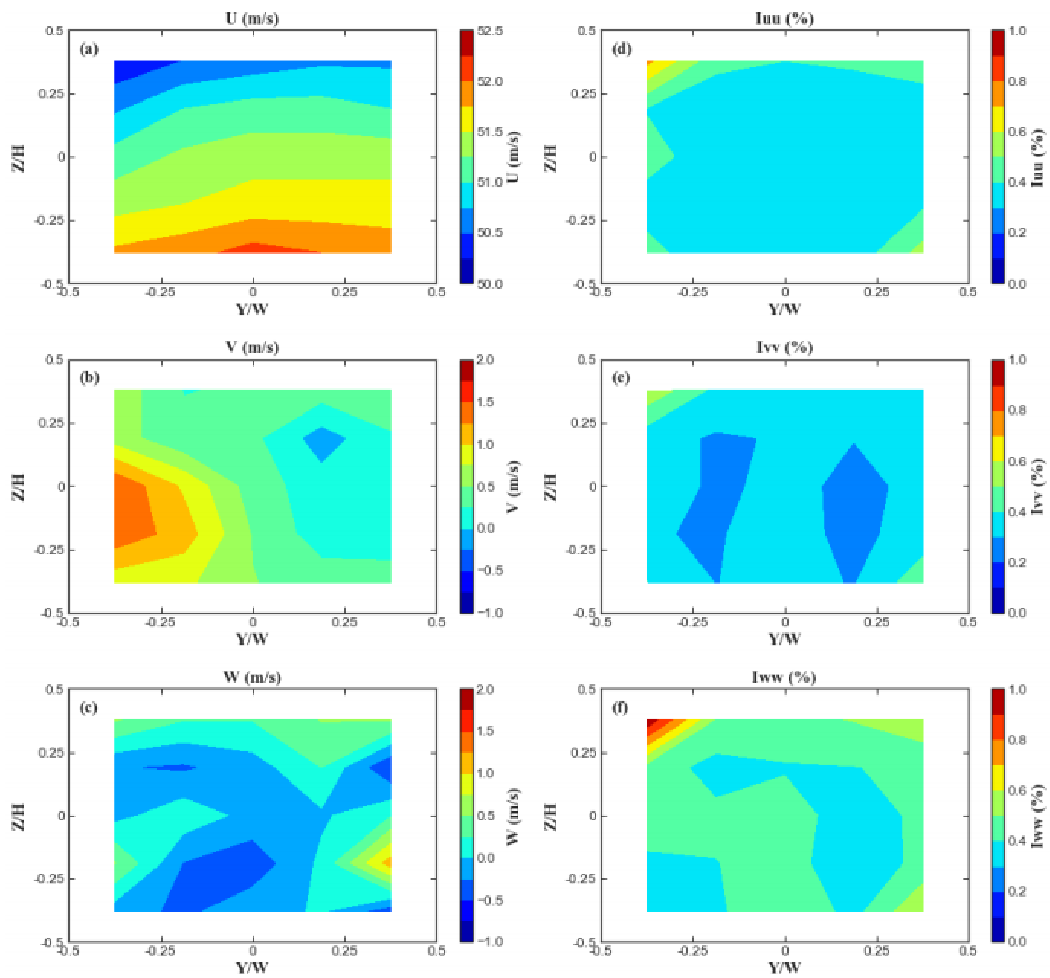

Fig. 16 Velocity and turbulence contour plots for Ψ = -29 deg, Max Wind, Max Tunnel Speed, All Buildings case.

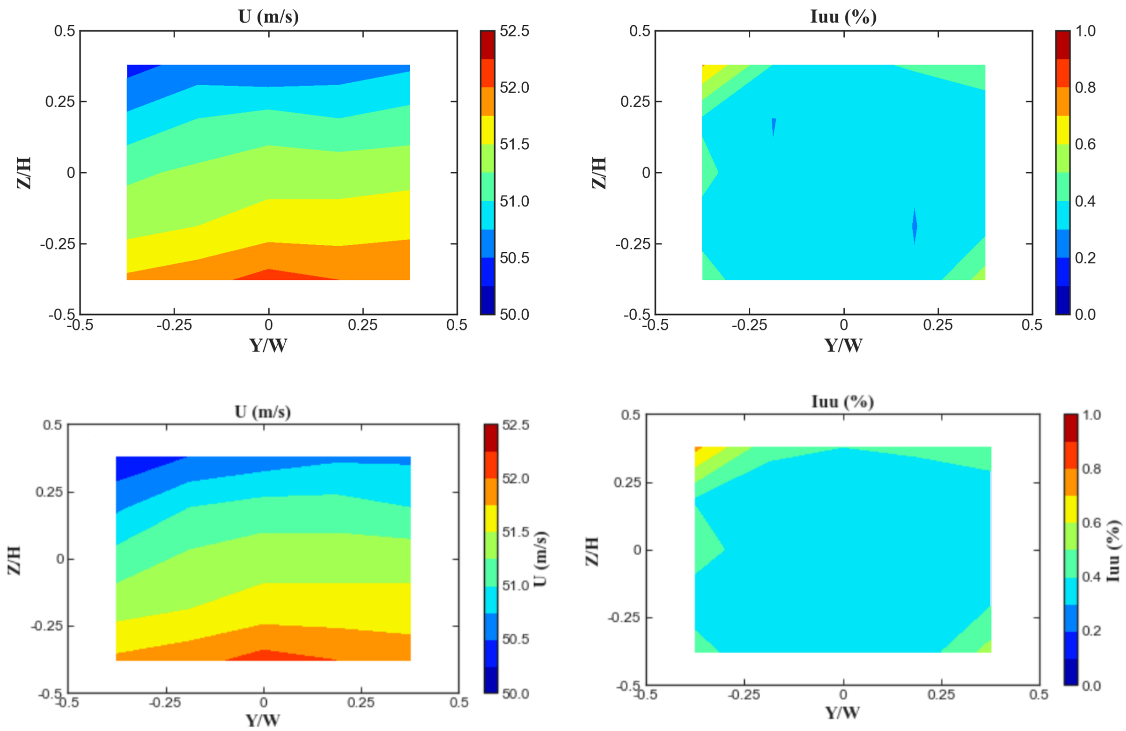

Fig. 17 ***U* velocity and I_{uu} contour plots for Ψ = -29 deg, baseline (no wind, no buildings) and extreme (max wind, all buildings) cases at max test section speed.**

and the maximum wind, all buildings case or extreme case are plotted in Figure 17.

By comparing these two extreme cases more closely, the lack of significant change in the test section due to either onset winds or upwind buildings is negligible. It is possible that any generated turbulence from the buildings either decayed upstream of the inlet or any turbulence was filtered by the inlet treatment. However, it is important to recall the limitations of the wind generated in this test. It is not possible to conclude that this data represents all wind data, and it is possible that higher, more consistent winds could in fact impact the test section turbulence levels (although this is unlikely; see Figure 22 discussion).

In order to confirm these results, other onset wind angles were studied. These angle studies were performed at maximum wind and a test section speed of 20 knots (10.3 m/s). Though many tests of interest were performed at the full operational speed of 100 knots, many utilize a lower speed. Though the tunnel is infrequently run below 40 knots, some tests are performed at lower test section speeds near 10 and 20 knots. It was thought that lower test section speed would have increased sensitivity to turbulence. In this Ψ study, building configurations eliminated buildings that were outside a certain distance range from the inlet's intake region. The U velocity and I_{uu} plots are shown below in Figures 18 to 21 for a test section speed of 20 knots and maximum wind.

Turbulence in I_{uu} exceed the 0.5% limit at most points in all cases. In fact, the case with the lowest overall turbulence levels in the test section comes when the onset wind is centered on the Googleplex (Figure 18).

Next, studies were performed at a variety of test section speeds (Figure 22). In addition, because the onset wind speed was heavily limited during these tests, a wind speed to test section speed ratio, V_{wind}/V_{ts}, can be used to extrapolate data about higher wind speeds. These tests were performed as centerpoint studies, as the nature of the study called for multiple conditions changes that made it difficult to execute full area surveys.

A linear fit was applicable to these plots, allowing for the data to be extrapolated. By extrapolation, the effects of higher winds can be estimated for more cases. Test section values at and above 40 knots kept turbulence values near or below the 0.5% threshold in all wind and building conditions; the linear fit for this data set has a slope close to zero, and other cases with larger ratios indicate that the linear trend holds at higher ratios. This indicates that, at these higher test section speeds, there is minimal sensitivity to onset wind at any speed. There is also no noticeable difference in turbulence levels between the no building and all buildings case, further reinforcing this statement. When looking at the

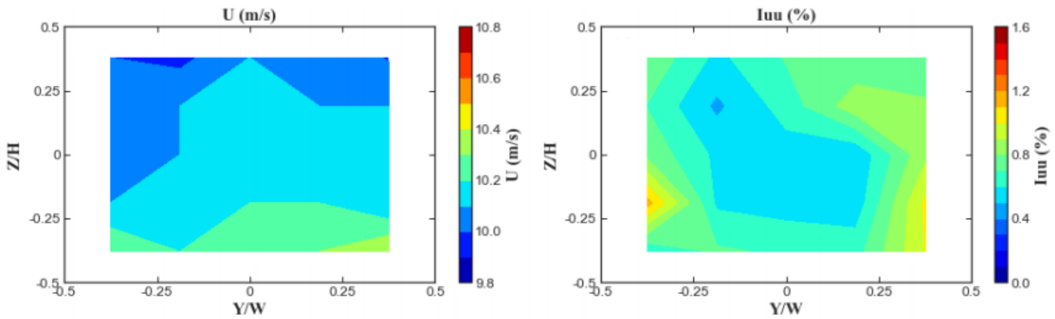

Fig. 18 Ψ = -29 deg, Max Wind, 20 knots Test Section Speed, all buildings survey.

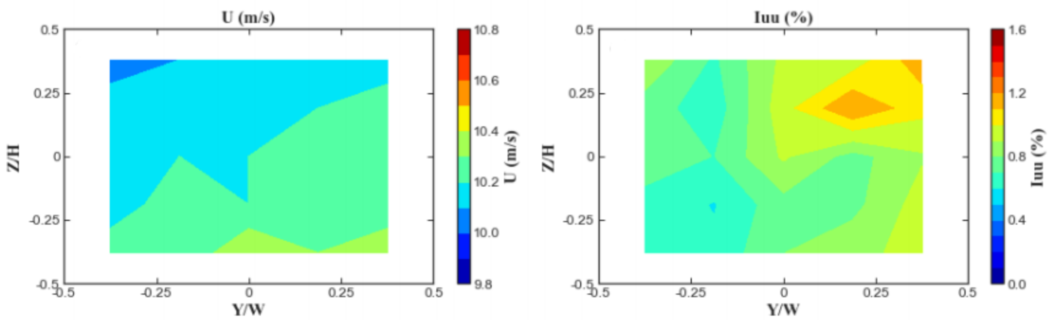

Fig. 19 Ψ = -38.06 deg (wind centered over Building N258), Max Wind, 20 knots Test Section Speed, Existing buildings survey.

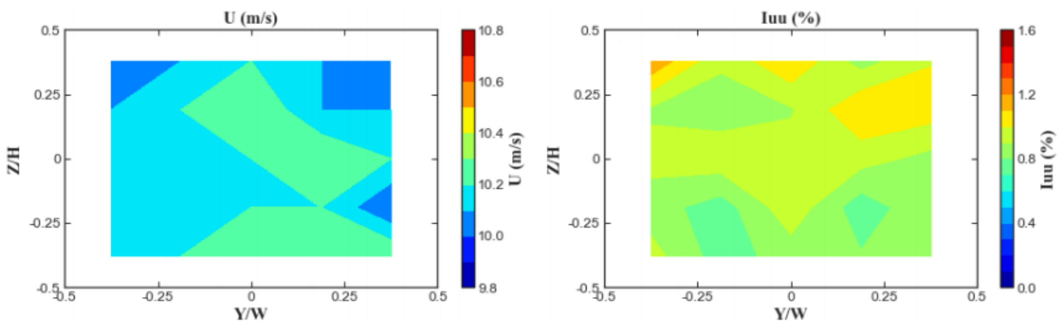

Fig. 20 Ψ = 0 deg, Max Wind, 20 knots Test Section Speed, Google and NASA trailer buildings survey.

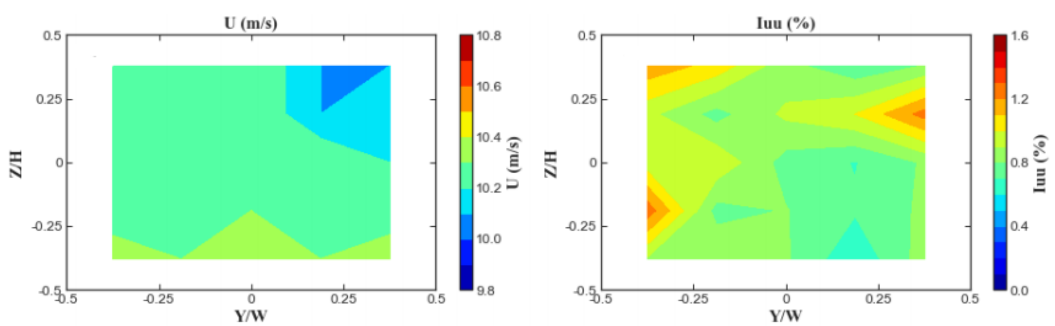

Fig. 21 Ψ = 22.32 deg, Max Wind, 20 knots Test Section Speed, (centered over MVC largest building), Google and NASA trailer buildings survey.

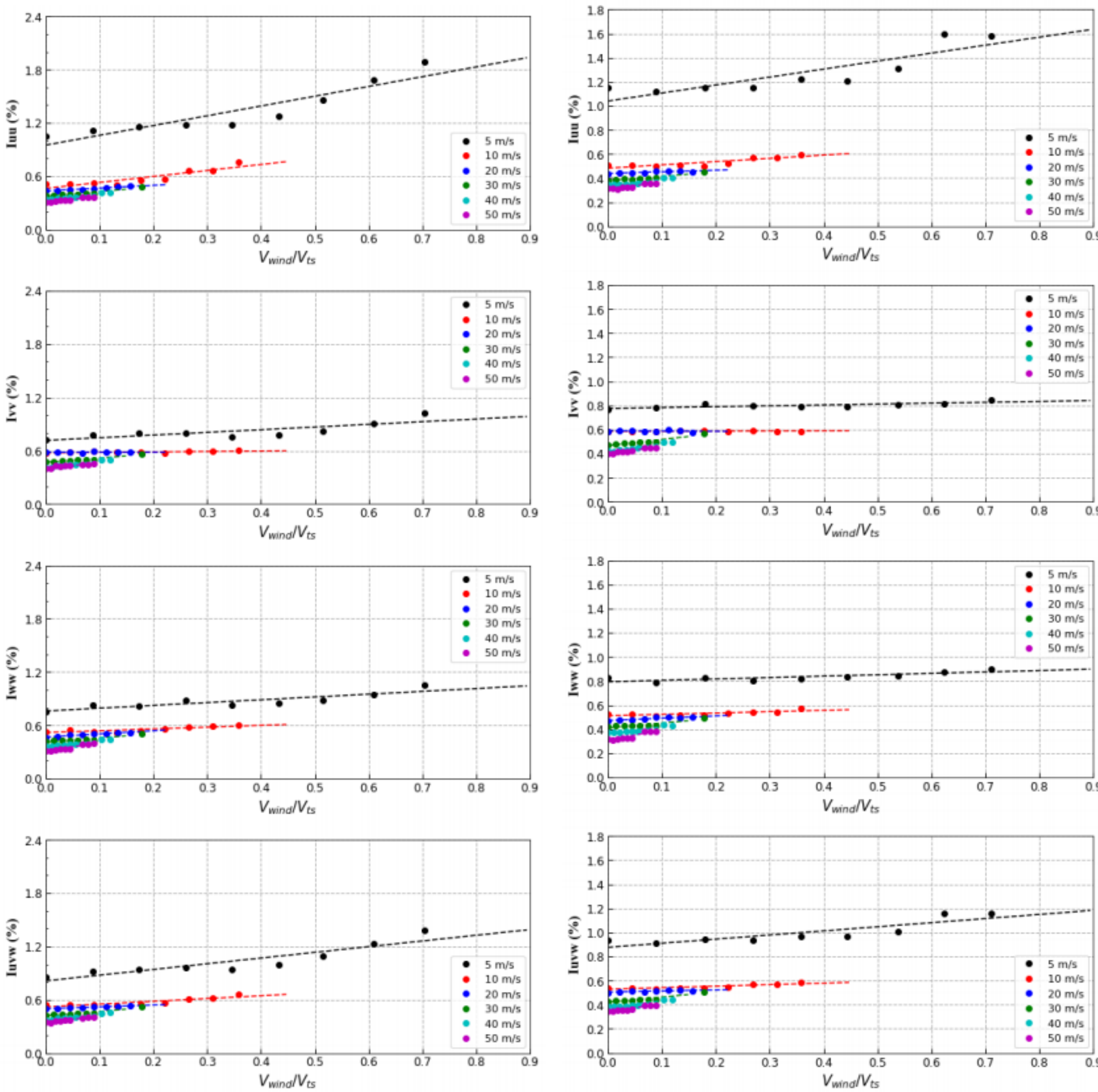

Fig. 22 V_{wind}/V_{ts} **Centerpoint Plots at Ψ = -29 deg, for No Buildings (left) and All Buildings (right).**

lower test section speeds, a reduction in turbulence overall is seen. Though the slope of the trendline appears consistent, noting the change in y-axis values reveals that the case with buildings experiences overall lower turbulence values. Therefore, turbulence values are kept below the required threshold in higher test section speeds; cases at lower speeds are above the required threshold in both cases, and the addition of buildings leads to overall lower turbulence levels.

B. Effects of Generic Blockages on Tunnel Performance

Since the existing and future buildings did not yield significant changes in test section turbulence, further studies were performed to determine what blockage configurations would push turbulence values past acceptable limits. Generic blockages will be compared in two different ways: as an effect of height at a set distance and as an effect of distance at a set height. All tests were performed with maximum wind, at a test section speed of 50 knots.

The first comparison will be of different blockage heights located 12 ft from the front of the inlet. Tests were performed at a test section speed of 50 knots with maximum wind. This configuration was placed with one edge on the inlet centerline, as shown on the right in Figure 11. Only I_{uu} plots will be shown for these results (Figure 23).

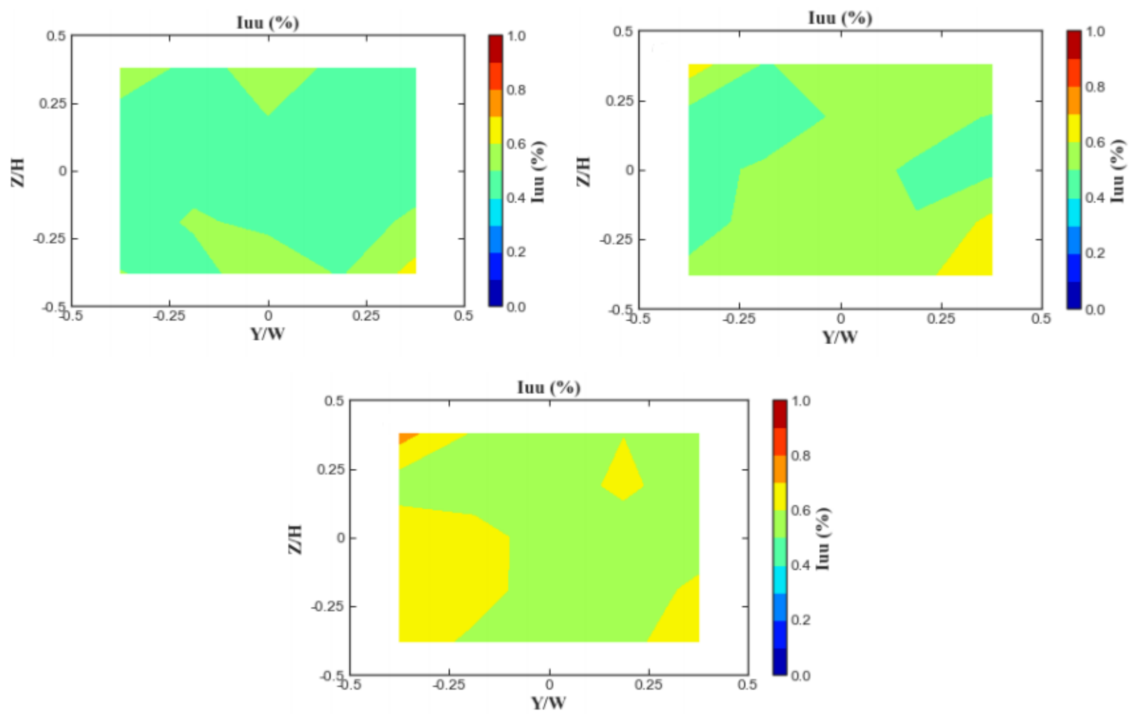

Fig. 23 50 knots, max wind for generic blockages 12 ft from inlet; 1ft tall (top left), 2ft tall (top right), 4ft tall (bottom).

An increase in turbulence levels can be seen as the height of the blockages increases. The 1-ft case is the only case with most values below the 0.5% threshold, though some values are above this limit on the edges of the measured region. The 4-ft case only has values above the threshold, indicating buildings at this height and distance would not be permissible for maintaining test section turbulence levels. However, since a majority of values in the 2-ft case are near the 0.5% threshold, it will be used as the limit. This sets a full scale limit of 100-ft tall, 600 ft from the inlet for new construction.

Next, the impact of distance can be studied, shown in Figure 24. This was studied using 1-ft tall blockage, centered on the inlet centerline. These studies were performed at full test section speed of 100 knots and maximum wind. Turbulence values at this height did not cause significant changes at varied distances. The 2-ft distance case has some values above the threshold, but not to the same extent as the 4-ft tall blockage 12 ft upstream. This sets the limit at the scaled 2-ft distance case where most of the values are near or above the limit.

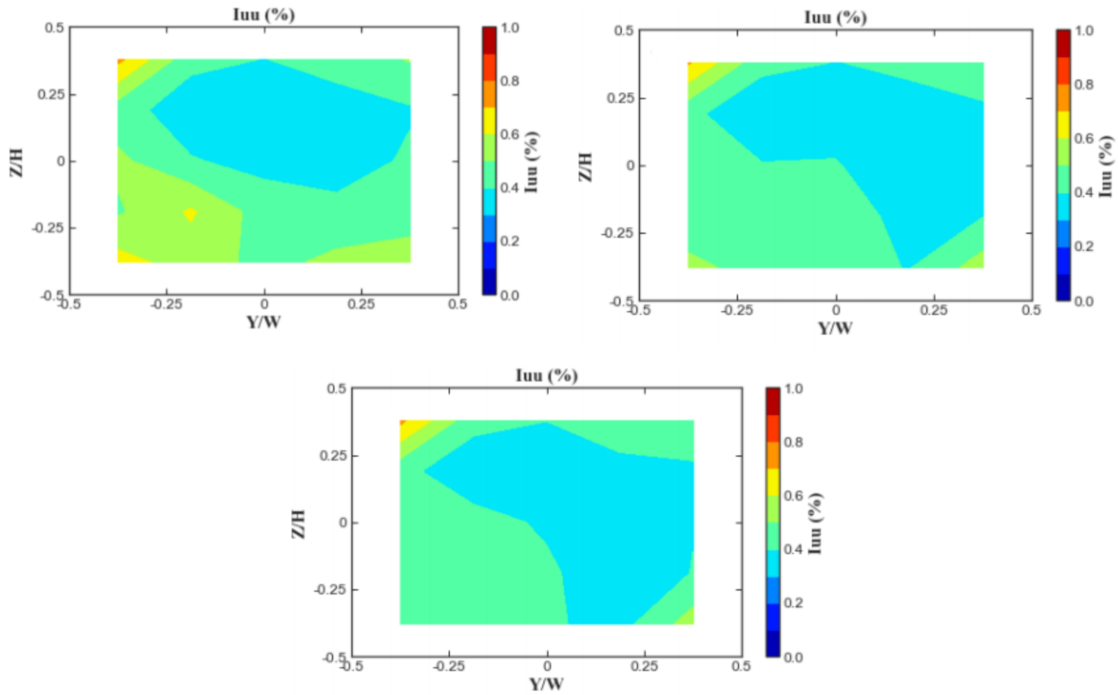

Fig. 24 50 knots, max wind for 1-ft tall generic blockages; 2-ft (top left), 4-ft (top right), 8-ft (bottom) from inlet.

C. Analysis of Results

Impact due to the new construction upstream of the inlet was found to be minimal for tunnel test section operating speeds at 40 knots (20.5 m/s) or higher. The new construction of the Googleplex buildings did not impact test section turbulence at a variety of wind speeds and onset angles, and test section speeds. When examining wind and test section speed ratios, limited sensitivity to wind above 40 knots was observed. A small reduction in turbulence was noted with the new Googleplex buildings, in cases with lower test section speed. In determining what constructions would impact turbulence levels, it was found that new constructions would have to be within 600 ft of the inlet at a minimum height of 100 ft; this is a highly unlikely scenario for a new construction.

V. Conclusions

Testing utilizing the 1/50th-scale model of the 80x120 tunnel was performed to examine the effects of a new construction occurring upstream of the tunnel's open circuit inlet on the test section turbulence values. Testing had been performed previously in 2014, examining different building models and blockages, and found minimal impact on test section turbulence. However, this testing was performed without atmospheric winds blowing over the buildings. This paper reports the first testing performed to date on the 80x120 inlet as-built under controlled test conditions for wind magnitude and wind onset direction for a variety of buildings in the inlet external flow field, including no buildings (the control case). Due to the complex nature of the buildings and the variety of wind directions, a set of "worst case" conditions were created, including modeling the buildings as a 2D silhouette blockage and focusing on a set of onset wind angles that would maximize flow over these buildings. In addition to testing building geometries, a set of generic blockages was used to find the limits of allowable construction in front of the inlet.

Tests involving the new Googleplex buildings, as well as existing buildings in the area, found no noticeable impact on test section turbulence. Values largely remained below the required design turbulence threshold of 0.5%. There were no noticeable changes from different wind speeds, angles, or test section speeds, and most values stayed below the required turbulence threshold. When examining results at lower test section speeds of 10 and 20 knots, values tended to exceed these limits in all cases but were reduced by the presence of the new Googleplex. Therefore, the addition of the new Googleplex buildings will not impact testing at the normal operating speeds of 40 knots or higher, and in fact improve conditions at the less common tests involving lower test section speeds, although with turbulence levels still higher than the threshold.

In testing generic blockages, new limits can be set for future building construction. It was found that the first noticeable change in turbulence came at a full scale distance of 600 ft at 100-ft tall. In addition, a building 50-ft tall, 100 ft away would generate excess turbulence detectable in the test section. However, building construction is highly unlikely in this region. Therefore, though each new construction in the region should be scrutinized, the 80x120 test section turbulence levels are not easily affected by upwind blockage of its inlet.

Acknowledgements

We would like to thank the Air Force for allowing us access to the National Full-Scale Aerodynamics Complex 80- by 120-Foot Wind Tunnel for the necessary testing and all of their assistance, and Barry Porter and Dr. Alan Wadcock for their mentorship throughout all testing. Lastly, we thank Dr. William Warmbrodt for all the continued support and guidance through this project.

References

[1] 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.

[2] 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.

[3] Bjarke Ingels Group Heatherwick Studio, "Bayview Concept Development Plan," June 17, 2016.

[4] Salazar, D., and Yuricich, J., "Turbulence Intensity at Inlet of 80- by 120-Foot Wind Tunnel Caused by Upwind Blockage," 2014. NASA/CR—2014–216637.

[5] Dromiack, H., Chitan, A., Schoultz, S., and Wadcock, A., "Effect of Upstream Buildings on the Aerodynamic Flow Quality in the Test Section of the National Full-Scale Aerodynamics Complex 80- by 120-Foot Wind Tunnel," 2019. NASA/TM—2019–220053.

[6] 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.

[7] Dromiack, H., and Wagner, L., "Inlet Performance of the NFAC 1/50th Scale 80- by 120- Foot Wind Tunnel," *AIAA SciTech*, 2021.