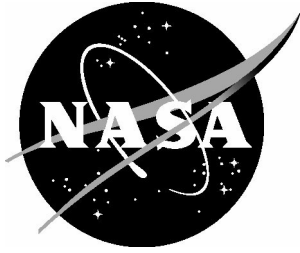


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Final Flow Survey of Langley 12-ft Low Speed Tunnel

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April 2026

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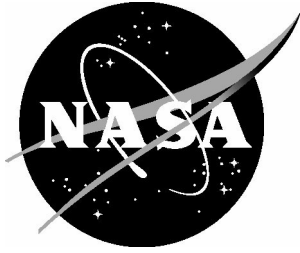
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Abstract

A dynamic pressure calibration was conducted in the NASA Langley 12-Foot Low-Speed Tunnel for the final year of its operation. The objective was to calibrate the wall-mounted pitot static probe, used to measure freestream dynamic pressure during normal tunnel operations, relative to the dynamic pressure recorded over a cross-sectional area of the test section. The survey provided a calibration factor to be applied to the wall probe to accurately reflect an area weighted average of the air flow through the test section. Heat maps were also generated to visually show areas of the test section where pressure measurements differ from the wall probe reading. This paper details the survey probe rake used and the methods for generating a calibration value for the tunnel as well as the implementation of that value. This calibration value serves as a correction factor that any testing in the tunnel would apply to the recorded data.

Introduction

Flow surveys are a vital part of wind-tunnel operations and should be conducted regularly to ensure the continued calibration of the tunnel measurements as well as the quality of the flow across the test section. The flow survey in the present study used a rake with a linear array of pitot-static probes evenly spaced across the test section. This linear array was mounted on a roll-rig so that the rake could be rotated and was positioned at the axial tunnel station where a wind-tunnel model balance moment center is approximately located. An area weighted average of the survey probe measurements was used to calibrate the wall-mounted pitot-static probe used to set and monitor the tunnel speed during normal operations.

This tunnel survey had a secondary objective of supporting a series of check-standard tests being conducted in both the 12-Foot Low-Speed Tunnel and the 20-Foot Vertical Spin Tunnel, shown in Figure 1. These tunnels are scheduled to be replaced by the new Flight Dynamics Research Facility by beginning of 2026. The check-standard tests will be repeated in the new tunnel and the flow survey will be used to help clarify any differences between the test results of those tunnels.

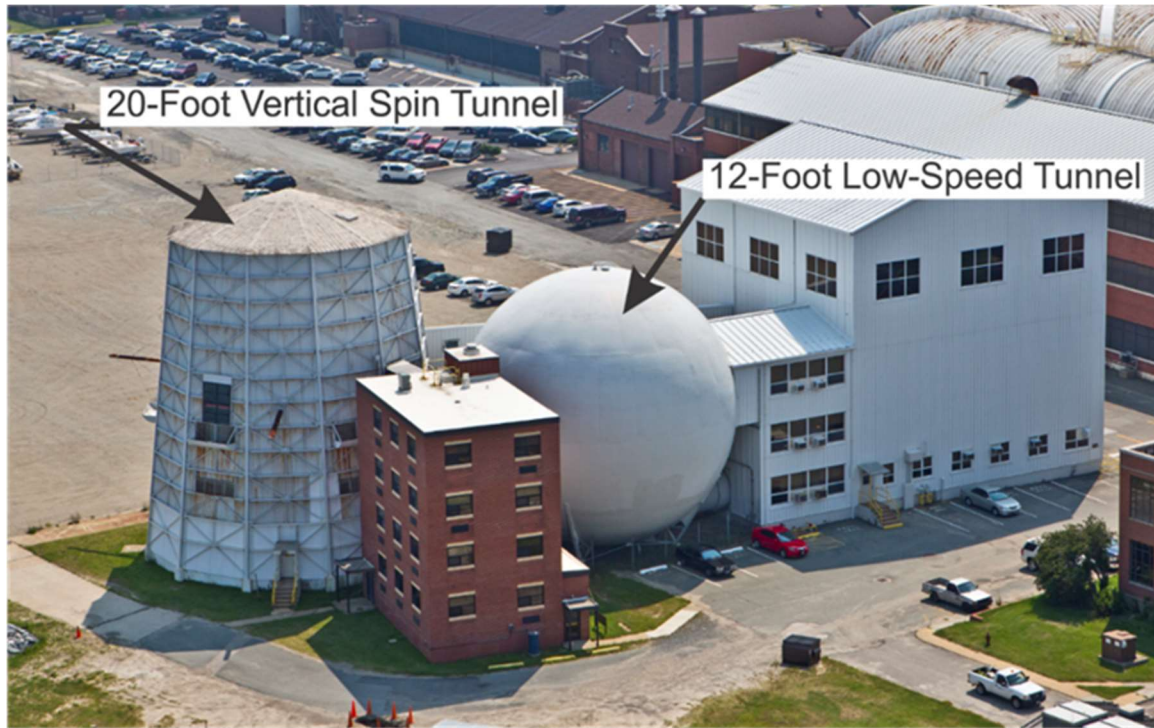


Figure 1 – Photo of 20-Foot Vertical Spin Tunnel and 12-Foot Low-Speed Tunnel.

12-Foot Tunnel Background

The 12-Foot Low-Speed Tunnel (LST), illustrated in Figure 2, was originally designed and developed to test the stability and control of dynamically-scaled models in a free-flight test environment (Ref. 1). This untried design, created by Charles H. Zimmerman, would feature a tilting test section so that the flow angle could be adjusted to match the glide slope of a model. When the angles are matched, the model aircraft could generate enough lift to “fly” in the test section. The models were controlled remotely by a pilot stationed under and in front of the fan blade while tunnel speed and tilt were controlled by tunnel operators. While in flight, pilots and observers could test out the stability of given aircraft designs.

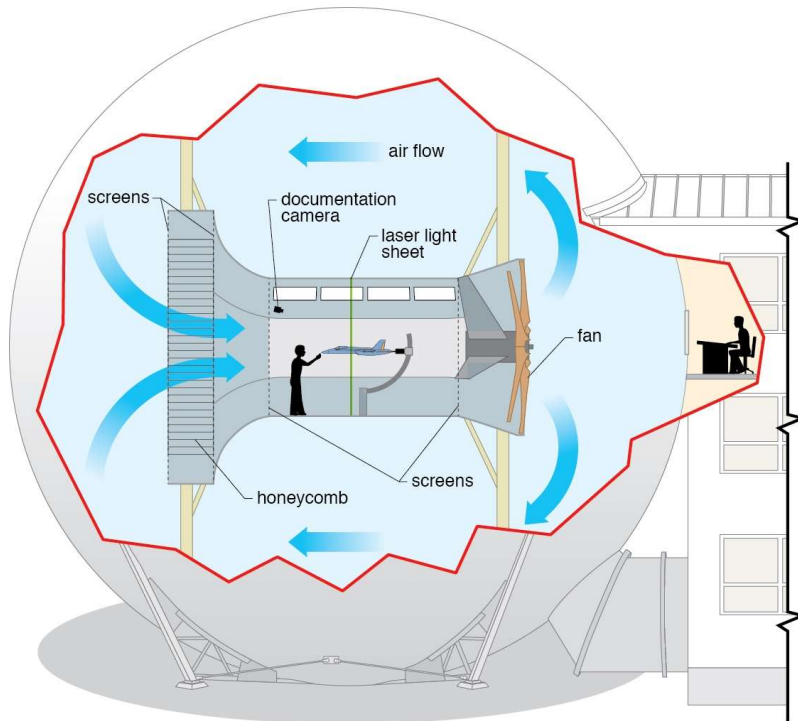


Figure 2- Illustration of 12-Foot Low-Speed Tunnel.

The 12-ft LST first began as a smaller 5-ft prototype in 1937. This proof of concept would be used to test the overall efficacy of a tilting, free flight tunnel. Having successfully proven the concept, the 12-ft version was approved, and construction completed in 1939.

After years of operating in this manner, the test section was eventually locked out and no longer capable of pitching. In 1958, with the lessening of war-time demand on the neighboring Langley Full Scale Tunnel test schedule adjacent to the 12-ft facility, more exploratory free-flight tests were able to be shifted to the Full-Scale Tunnel. Boasting a 30 x 60 ft test section, the Langley Full-Scale Tunnel offered more freedom and less risk when conducting free-flight testing. Although this massive test section was fixed, the wide open area could provide enough room and air speed where tilting was not necessary. Another benefit of the larger test section, models could be larger and more sophisticated than the typical small balsa wood models flown in 12-ft. With all these benefits, the free-flight testing technique was transferred over, and the 12-ft tunnel was converted for the conventional captured force-test studies and the test section permanently fixed in a horizontal attitude. While some quadcopter free flight tests would be conducted, the tunnel would not tilt again. After its conversion, the 12-ft LST served as a low operating cost, rapid testing option for prototyping both aircraft and atmospheric entry vehicles. The tunnel has been a valuable concept development environment offering a wide range of static and dynamic captive test techniques such as pitch-pause, forced oscillation, constant rate, arbitrary motion, 1- to 3- DOF free-to-rotate, flow visualization, and still the occasional free-flight test. Not only did the tunnel offer a wide variety of more classic test techniques, but it also functioned as a “sandbox” to allow researchers to test out and further expand testing methods such as Design of Experiments and Programed Test Inputs.

Due to the aging of the facility, a new tunnel was proposed to combine the capabilities of the VST and the 12-ft LST in to one wind tunnel: the Flight Dynamics Research Facility (FDRF), shown in Figure 3. The FDRF is scheduled to be operational in 2026 and will be a 20-ft, vertical tunnel powered by 4 individual fans at the base of the building. This tunnel will enhance current techniques by utilizing all the existing test capabilities in an environment with better flow quality and a larger tunnel dynamic pressure range. The current 12-ft tunnel model support equipment is to be integrated into the FDRF along with the Rotary Balance System from VST. The FDRF will be capable of running a test on one system while simultaneously preparing for a test on the other, allowing rapid transition between two different models.



Figure 3 - Illustration of the new Flight Dynamics Research Facility (FDRF).

Symbols and Nomenclature

A	Area	q_t	Tunnel area averaged dynamic pressure
b	Y-Intercept	q_w	Wall probe measured dynamic pressure
DTC	Digital Temperature Compensation	r	radius, ft
$FDRF$	Flight Dynamics Research Facility	RBS	Rotary Balance System
FO	Forced Oscillation	RPM	Fan Rotations Per Minute
LST	<i>Low-Speed Tunnel</i>	VST	Vertical Spin Tunnel
m	Line Slope	ε	Rate offset angle, deg
n	Number of survey area segments	ϕ	Angle of rake rotation, deg
q	Dynamic pressure, psf	θ	Strut pitch angle, deg
q_{set}	Tunnel set dynamic pressure, psf		
q_p	Rake measured dynamic pressure, psf		



Figure 5 – Flow survey rake attached to the roll oscillation rig on the C-Strut.

Instrumentation

The following instrumentation and calibration values were used throughout the test.

Survey Rake

For the flow survey in the 12-ft LST, a 14-probe rake measuring 10 feet in span was used (Figure 5). Each probe was a differential pitot-static probe 0.25 inches in diameter and 12 inches long measuring impact pressure. The probe locations were mirrored left and right from the center of the probe at radii of 3.0, 12.0, 24.0, 36.0, 44.0, 52.0, and 60.0 inches. The rake was mounted at its center point to a straight sting attached to the forced oscillation (FO) motor of the C-strut. The motor rotated the rake in 10-degree roll increments from 0 to 180 degrees. The tips of the survey pitot-static probes were 72.75" downstream of the test section inlet screen with the center of rotation being at the default test height of 67" above the tunnel floor, which is commonly used for testing in this tunnel.

Wall Probe

A key objective of the flow survey is the calibration of the wall-mounted pitot-static probe, shown in figure 4. Mounted high on the test section left wall (looking up stream) and 45 inches downstream of the entrance screen. The probe extends 10.5 inches off the wall and is the primary instrument used to acquire tunnel pitot-static pressure for flow speed determination during testing. This pressure was measured by a newly

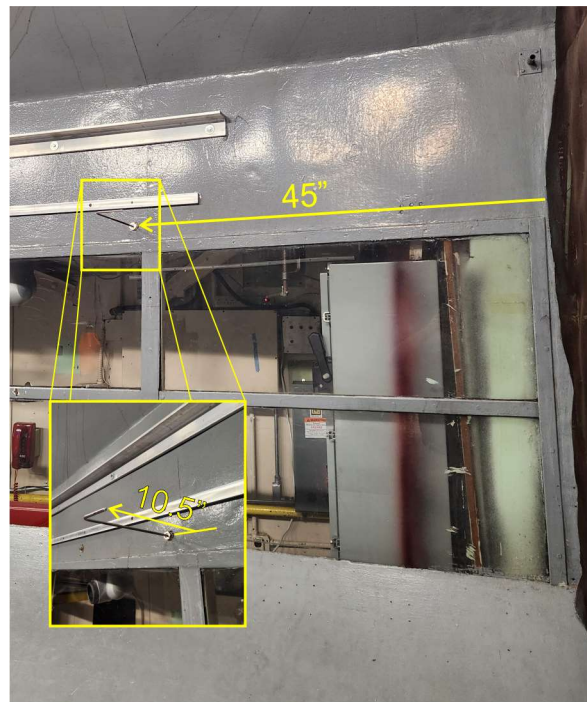


Figure 4 – Tunnel pitot-static probe

calibrated Druck LPX 9381 Pressure Sensor with a calibration of 0.00104083 psf/mV. The Druck signal is passed through a Dataforth Isolator Conversion using $0.650519 \text{ psf/mA} \times 16\text{mA}/10\text{V} = 1.0408304 \text{ psf/V}$.

Data Measurement and Acquisition

All the survey rake pressure ports were connected to a 32 port, 4" H₂O ESP Module that was interfaced with a digital thermally compensated (DTC) Initium Data Acquisition System shown in Figure 6.



Figure 6 - DTC Initium Data Acquisition System.

Atmospheric total pressure was measured by a newly calibrated Mensor CPG2500 Precision Pressure Indicator from a pressure line in an isolation canister, crafted from materials on hand, located in the control room, as shown in Figure 7. The Mensor linear calibration had a slope of 0.226319536 psf/mV with an intercept at -0.0380830346 psf.



(a) Mensor CPG2500



(b) Isolation canister

Figure 7 - Atmospheric pressure measurement.

Tunnel temperatures were determined using a Wyle Ice Point which used the ice point reference method to determine tunnel ambient temperatures. All atmospheric pressure, tunnel wall pressure, and temperature data was collected by the Neff 620 series Digital Data Acquisition system using a 10 second sample length at a rate of 200 samples per second. Analog signals were passed thru a 10 Hz low-pass 6-pole Butterworth filter prior to digitization.

Flow Survey Method

A pressure probe rake was placed inside the test section to sample a full cross section of the test section. A chosen dynamic pressure value (q_{set}) was selected, and the tunnel was maintained at that point. Using the wall dynamic pressure reading, the tunnel was operated in RPM hold mode where the fan RPMs were adjusted until a running average of the dynamic pressure was approximately the desired q_{set} . The running

average would be reset after the RPM was adjusted and the operator felt the airflow had stabilized. The running average was left running after reset and the effect of the RPM change judged by the operator around 10 to 15 seconds after starting the running average. The rake was leveled horizontally which was used as the starting point for the survey. This starting point would be considered as a rake angle of rotation (ϕ) of 0° . The rake was then rotated about the test section centerline in 10° increments until $\phi = 180^\circ$. At each 10° increment, the air stream was sampled for 10 seconds at a rate of 200 Hz for each ϕ increment. Once all points were measured, the average dynamic pressure recorded by the rake and the wall probe were calculated. This process is then repeated for all the q_{set} points of interest. For this survey, q_{set} was 0.25, 0.5, 1, 2, 3, 4, 5, 6, and 7 psf. After all the q_{set} points are completed, the average area weighted dynamic pressure of the rake is plotted against the average dynamic pressure of the wall probe and a line of best fit applied. The slope of this line then yields the calibration factor for the wall probe to reflect the overall average dynamic pressure in the test section.

Flow Survey Data Processing

For each datapoint in the flow survey, there is a time-history recording of the of static and total pressure of the rake probes, the tunnel wall probe dynamic pressure, and the temperature and atmospheric pressure measurements. The survey data acquisition program creates six folders for each survey. The folders are named:

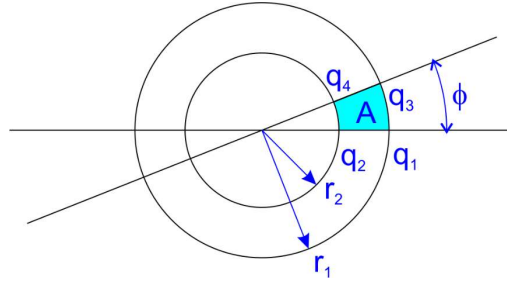
- AnalysisData – calibration fit values
- AvgData – averaged survey data
- CalibrationData – ESP and sensor zero values
- ComputedData – area weighted average segment values
- ProbeData – point averaged data
- TimeHistoryData – filtered 10 second probe time history data at 200 Hz.

The data record time history values were written to a tab-separated text file after the instrument calibrations were applied and bias zeros are subtracted. These files are written to the “TimeHistoryData” folder under the file name “(Survey#)_thEsp_(Run#)_(Point#).txt.”

A MATLAB® script was developed to replicate and verify the flow survey program output and include the standard deviation of the time history measurements of the various parameters. The probe mean and standard deviation of total and static pressure measurements can be computed from these time history files. Since 12-FT LST is only capable of achieving a max dynamic pressure of 7 psf, incompressible flow conditions can be assumed, allowing the use of Bernoulli's equation to relate dynamic pressure to the pressure measurements. Under these conditions, dynamic pressure for each probe location can be calculated using two approaches: either from the difference of the mean static and total pressures, or from the mean of the instantaneous pressure differences computed at each sample time. A comparative analysis revealed that the latter approach is preferred due to the high correlation between the static and total pressure measurements. While both methods yield identical mean dynamic pressure values, calculating the standard deviation is significantly more straightforward when using the mean of instantaneous pressure differences rather than attempting to propagate uncertainties through the difference of means.

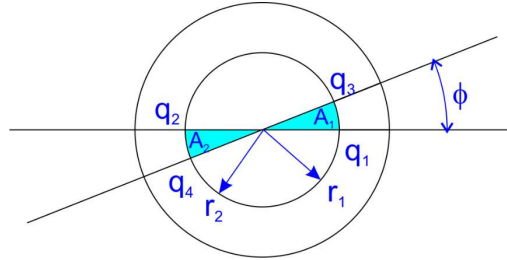
Beyond computing the standard deviation of the survey measurements, the MATLAB® script also served as an independent check of the survey program. This proved valuable as it resulted in a couple of corrections to the survey program. All the survey results presented here are from the MATLAB® script calculations.

The tunnel survey used an area weighted average of the rake probe measurements to compute the dynamic pressure calibration. For each segment as the rake is rotated the area weighted average pressure is:



$$q_{avg_A} = \frac{\phi}{8}(q_1 + q_2 + q_3 + q_4)(r_1^2 - r_2^2) \quad (1)$$

The segments at the center are computed as:



$$q_{avg_{A_{12}}} = \frac{\phi}{4}(q_1 + q_3)r_1^2 + \frac{\phi}{4}(q_2 + q_4)r_2^2 \quad (2)$$

The survey area average is determined by summing all the segment weighted averages divided by the total area.

$$q_t = \frac{1}{\pi r^2} \sum_{i=1}^n q_{avg_i} \quad (3)$$

Yawed C-Strut

An additional set of flow surveys were conducted to explore the flow distortion and calibration change caused by the C-Strut when yawed $\pm 90^\circ$. In this configuration the rake was mounted perpendicular to the sting and C-Strut as shown in Figure 8. The sweep of the survey rake is controlled thru the C-Strut pitch motor, as illustrated in Figure 9. With this change, the rake can now only sweep the 90° range of the C-Strut pitch motor. To survey the remaining 90° , the rake is remounted to the sting with a sweep angle offset. This approach neglected to account for some of the C-Strut geometry considerations that compromised the results and will be illustrated later. Consequently, the calibration values for these surveys are not presented and only the survey contours are provided.



a) C-Strut yawed -90°



b) C-Strut yawed -90°

Figure 8 - Yawed C-Strut survey rake configuration.

C-Strut yawed -90°

The -90° yawed C-Strut survey rake geometry is illustrated in Figure 10. The x, y coordinates for rake probe i relative to the tunnel centerline for a sweep angle θ are computed from:

$$x = x_c - (51.0 - 38.25) \cos \theta + r_i \cos(\theta - \varepsilon)$$

$$y = y_c + (51.0 - 38.25) \sin \theta - r_i \sin(\theta - \varepsilon)$$

The C-Strut yaw rotation axis is 10.252" in front of C-Strut center of pitch rotation. Consequently, when the C-Strut is yawed -90° (against right wall) the survey rig center of rotation is laterally offset 10.252" toward the right wall.

Two surveys were conducted with this C-Strut position. One with ($\varepsilon = 0^\circ$), as shown in Figure 9. The Strut was lowered to equalize survey tips (top and bottom) when fully vertical ($\theta = 90^\circ$). This resulted in the center point coordinates being:

$$(x_c, y_c) = (10.252, -14.5)$$

The second survey rotated the rake relative to the sting to $\varepsilon = 190^\circ$ with the center point coordinates

of:

$$(x_c, y_c) = (10.252, 1.2)$$

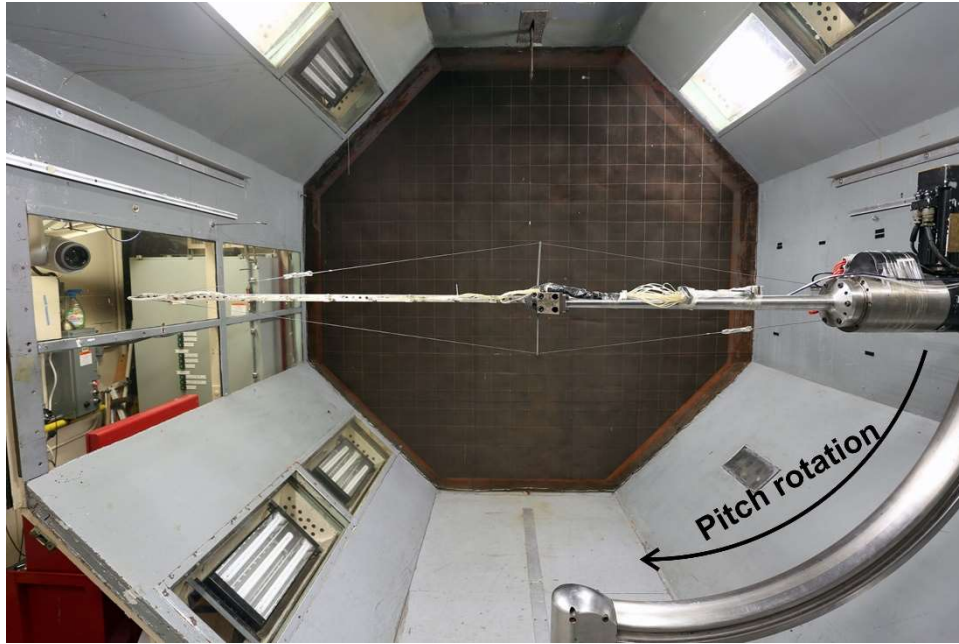


Figure 9 – Survey with C-Strut yawed -90° and $\varepsilon = 0^\circ$ rake orientation.

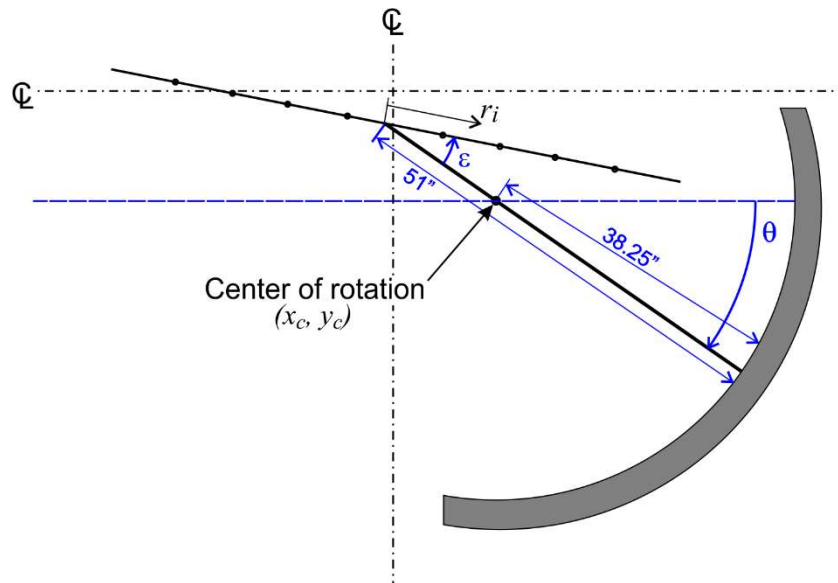


Figure 10 – C-Strut yawed -90° geometry.

C-Strut yawed +90°

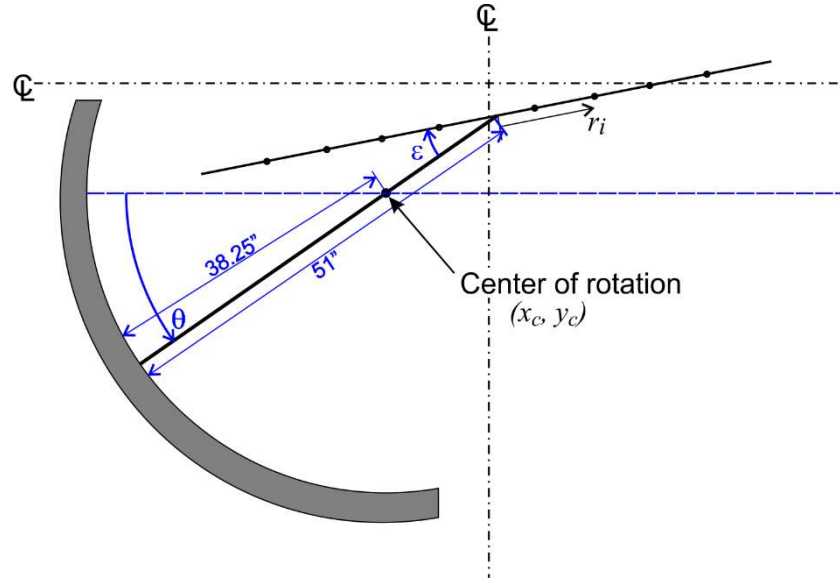


Figure 11 - C-Strut yawed +90° geometry.

The survey rake geometry with the C-Strut yawed +90° (strut along door side) is illustrated in Figure 11. The x, y coordinates for rake probe i for this configuration are:

$$x = x_c + (51.0 - 38.25) \cos \theta + r_i \cos(\theta - \varepsilon)$$

$$y = y_c + (51.0 - 38.25) \sin \theta + r_i \sin(\theta - \varepsilon)$$

Two surveys were taken with the C-Strut in this position. The first with:

$$(x_c, y_c) = (-10.252, -14.5), \varepsilon = 0$$

The second used:

$$(x_c, y_c) = (-10.252, 1.2), \varepsilon = 100$$

Results

Calibration Survey

The pressure ratio contours (q_t/q_w) of the calibration survey for each of the set dynamic pressures (q_{set}) are shown in Figure 12. Also shown in the figure is a dashed outline of the fan support structure. Of note is the flow deficit near the lower center of the survey and the higher flow rates along the outer edge of the survey. This can also be seen in figures 13 and 14, which show the horizontal and vertical probe measurements and pressure ratios, respectively. Also shown on the figures are the standard deviation bars which are indicative of the flow turbulence level. The shape of the flow variation appears to scale with the tunnel dynamic pressure, as seen in Figure 14.

The area averaged calibration values are shown in Figure 15 for different averaging radii. A linear fit to the measured values provides the calibration slope (m) and intercept (b). For the line of best fit, no forcing function was used to force a y-intercept at 0. This was chosen as to avoid nullifying the non-linearities observed at lower q_{set} points. When selecting a calibration value, one should consider the extent of the tunnel test area the model will inhabit. One should imagine a flat disk in the middle of the tunnel and apply the applicable calibration value for the space in which the model is tested.

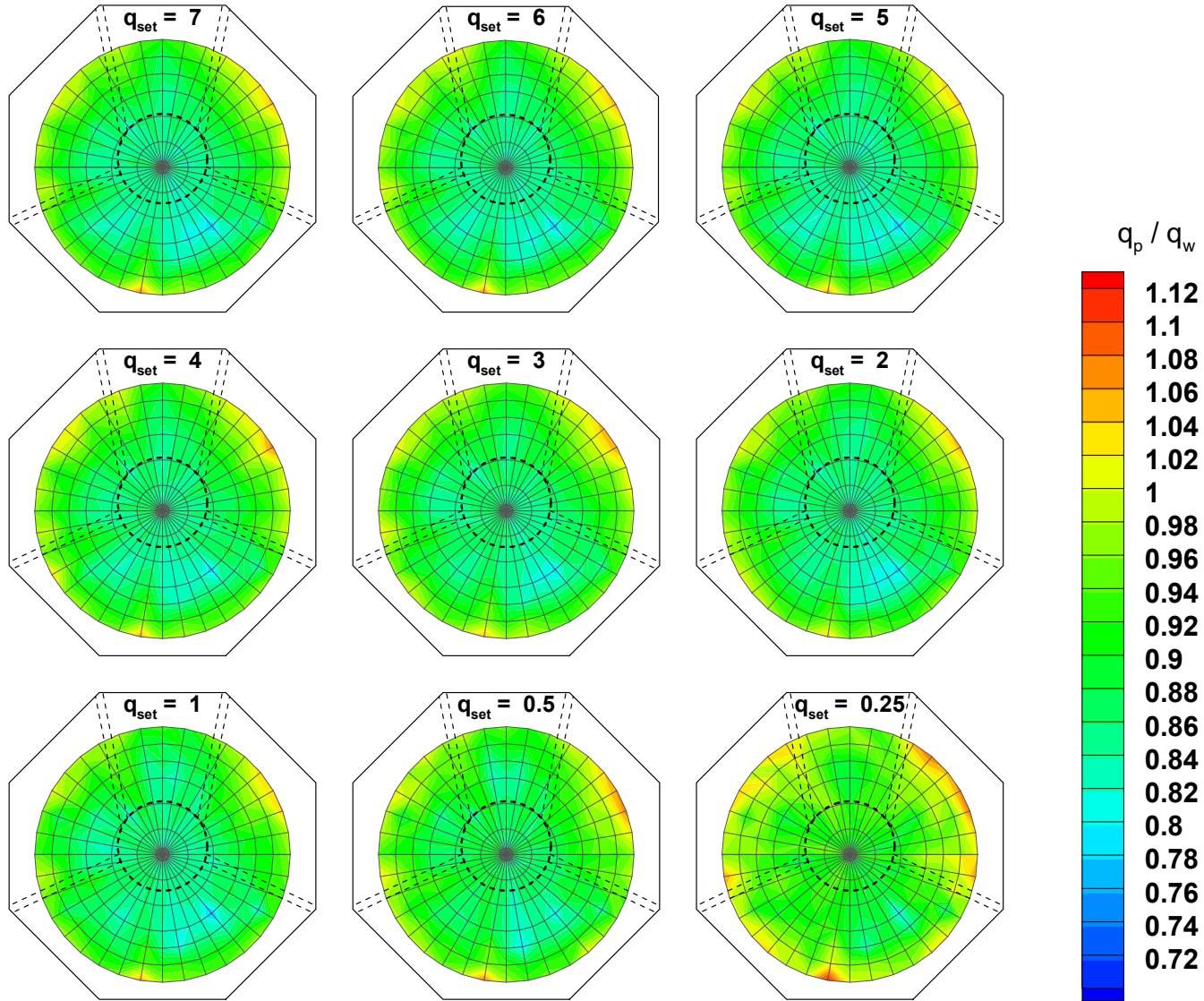


Figure 12 – Full survey contour plots of q_p/q_w ratio (looking upstream).

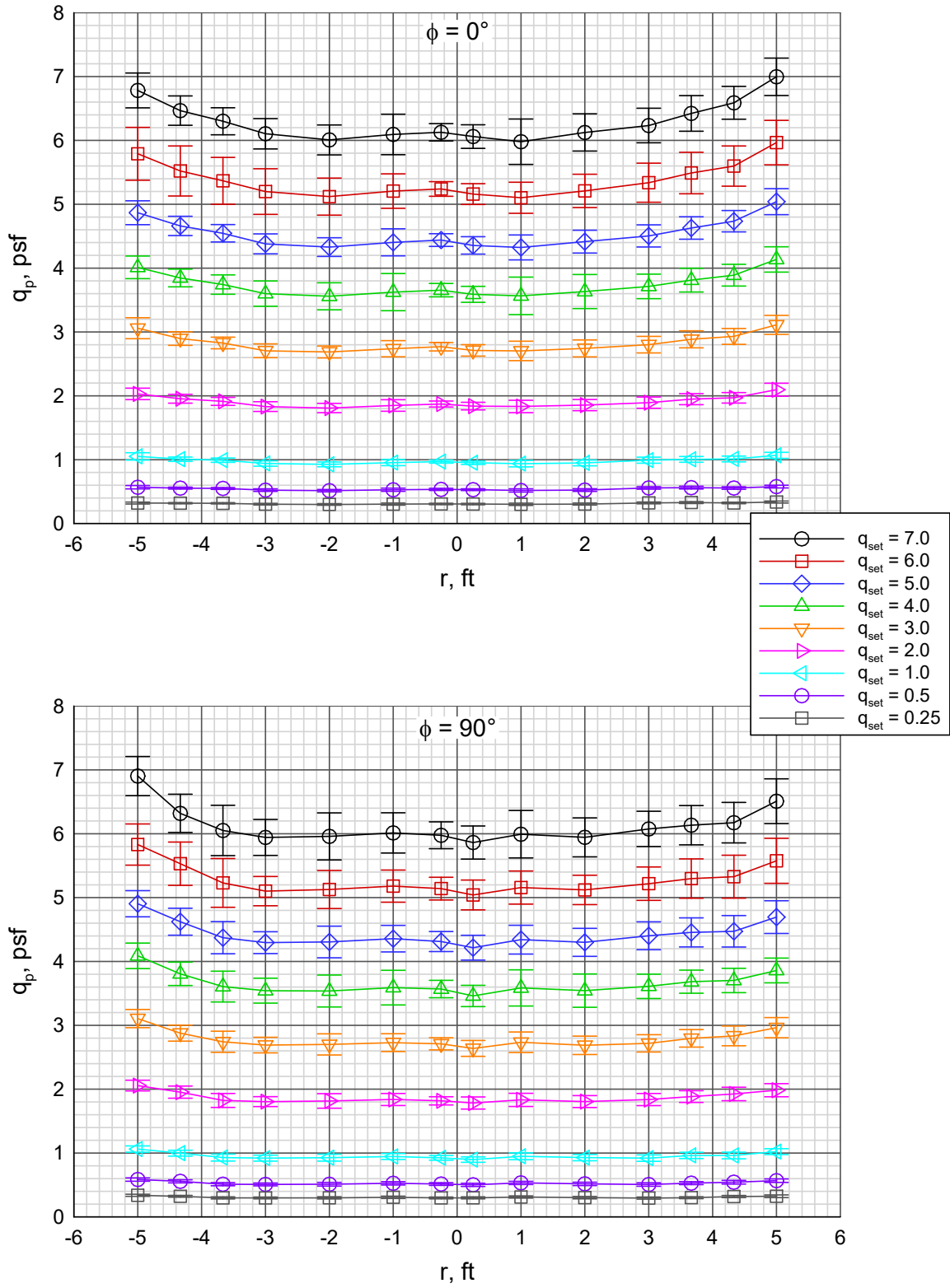


Figure 13 – Horizontal ($\phi = 0$) and vertical ($\phi = 90$) survey probe average and standard deviation values.

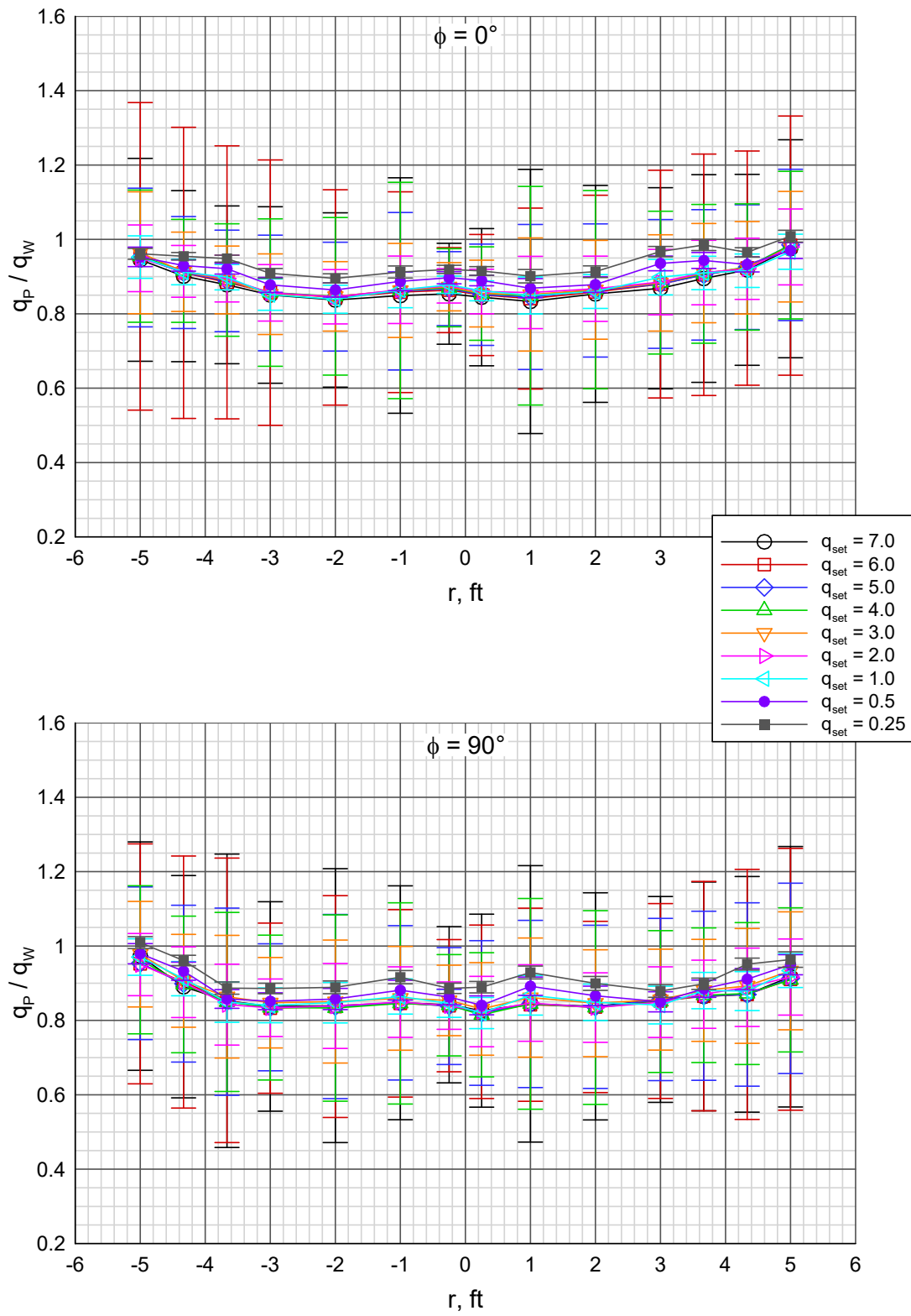


Figure 14 – Horizontal ($\phi = 0$) and vertical ($\phi = 90$) survey pressure ratio average and standard deviation values.

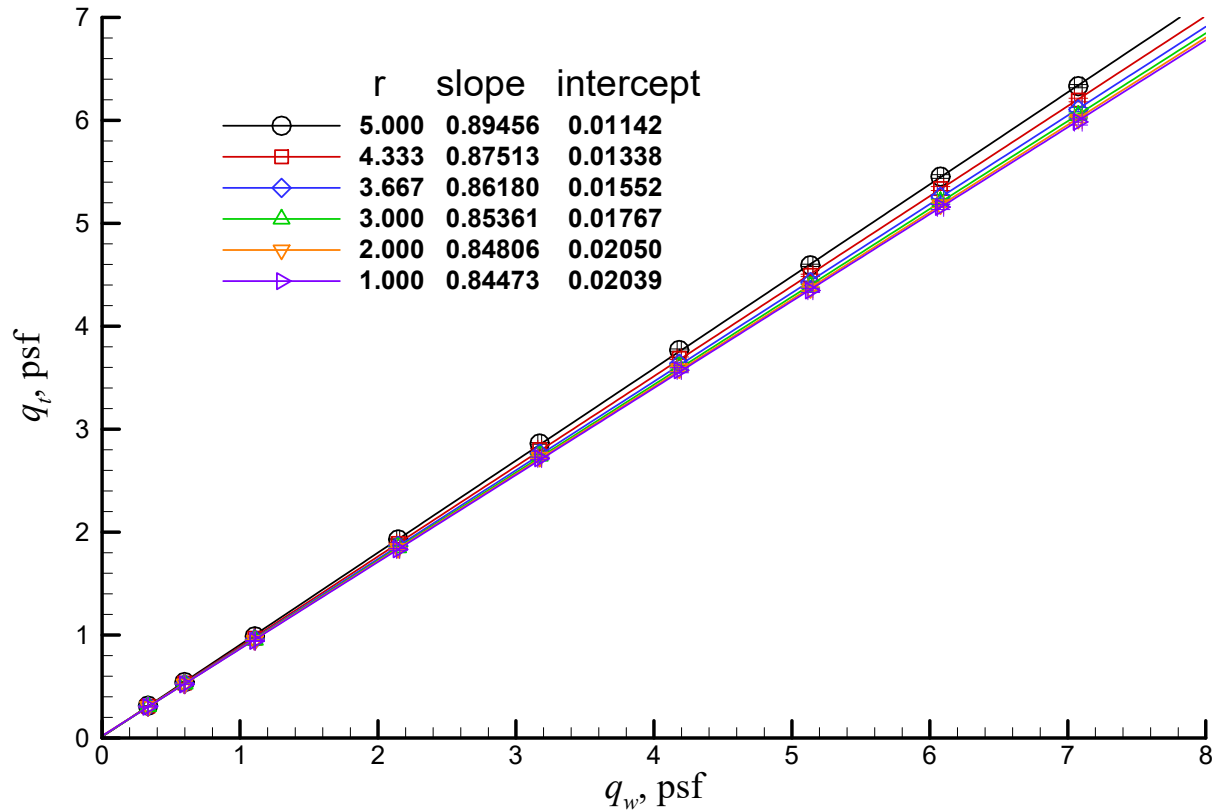


Figure 15 – Area-averaged dynamic pressure calibrations using only probes within a specified radii (feet).

Yawed C-Strut Effect

The results of the flow surveys conducted to explore the flow distortion and calibration change caused by the C-Strut when yawed $\pm 90^\circ$ are presented in figures 16-19. Also shown in these figures is an outline of the C-Strut location during the survey. The idea was to use the C-strut pitch motor to rotate the rake thru a 90° rotation, as shown in Figure 9. Then offset the rake orientation relative to the sting and rotate thru the final 90° to complete the sweep. This approach neglected to account for some of the C-strut geometry considerations that prevented completing a full sweep. Consequently, the calibration values for these surveys are not presented and only the survey contours are provided.

The main problem with using the C-Strut pitch motor for the survey sweep is that the strut center of rotation is 38.25 inches from the strut inside radius. Whereas the center of the rake was mounted to a 51-inch sting. This results in the center of the rake sweeping an arc. When the rake is then offset relative to the sting to complete the sweep the end points will not align. This was not anticipated during the test.

The effect of the yawed strut is evident in the contour plots which show the flow deficit around it and the accelerated flow away from it. When yawed $\pm 90^\circ$, the C-Strut generated a significant blockage effect directly up stream. This position creates enough of a blockage that the flow is altered across the whole test section. When the C-Strut is yawed $+90^\circ$ so that the back of the strut is on the same side as the tunnel's

wall probe, this effect will directly impact the tunnel dynamic pressure readings obtained from the probe. For this reason, the C-Strut should avoid being yawed $+90^\circ$ and instead be yawed to the -90° position if required.

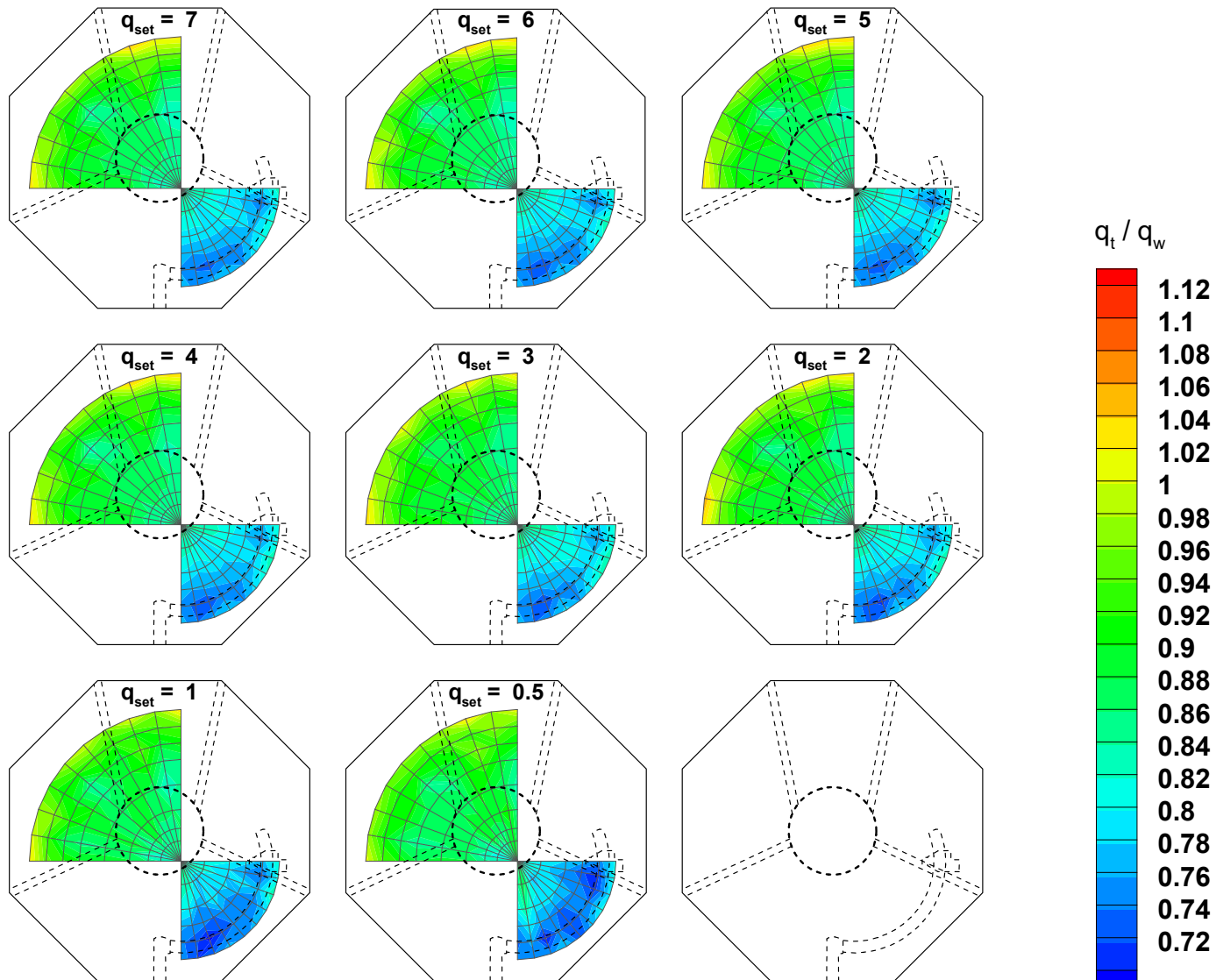


Figure 16 – Survey contour plots of q_t/q_w ratio for C-Strut yawed -90° and $\varepsilon = 0^\circ$ (looking upstream).

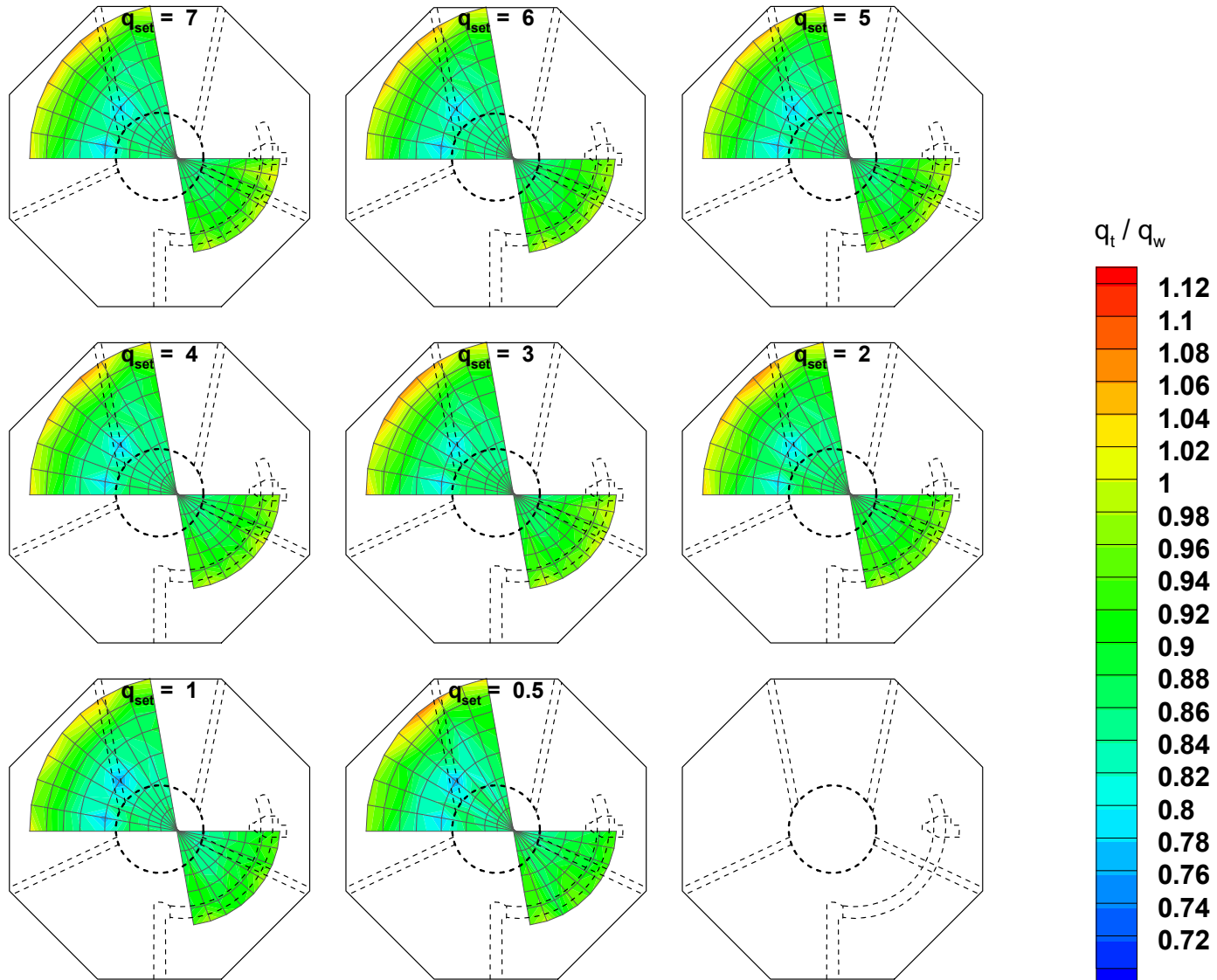


Figure 17 – Survey contour plots of q_t/q_w ratio for C-Strut yawed -90° and $\varepsilon = 190^\circ$ (looking upstream).

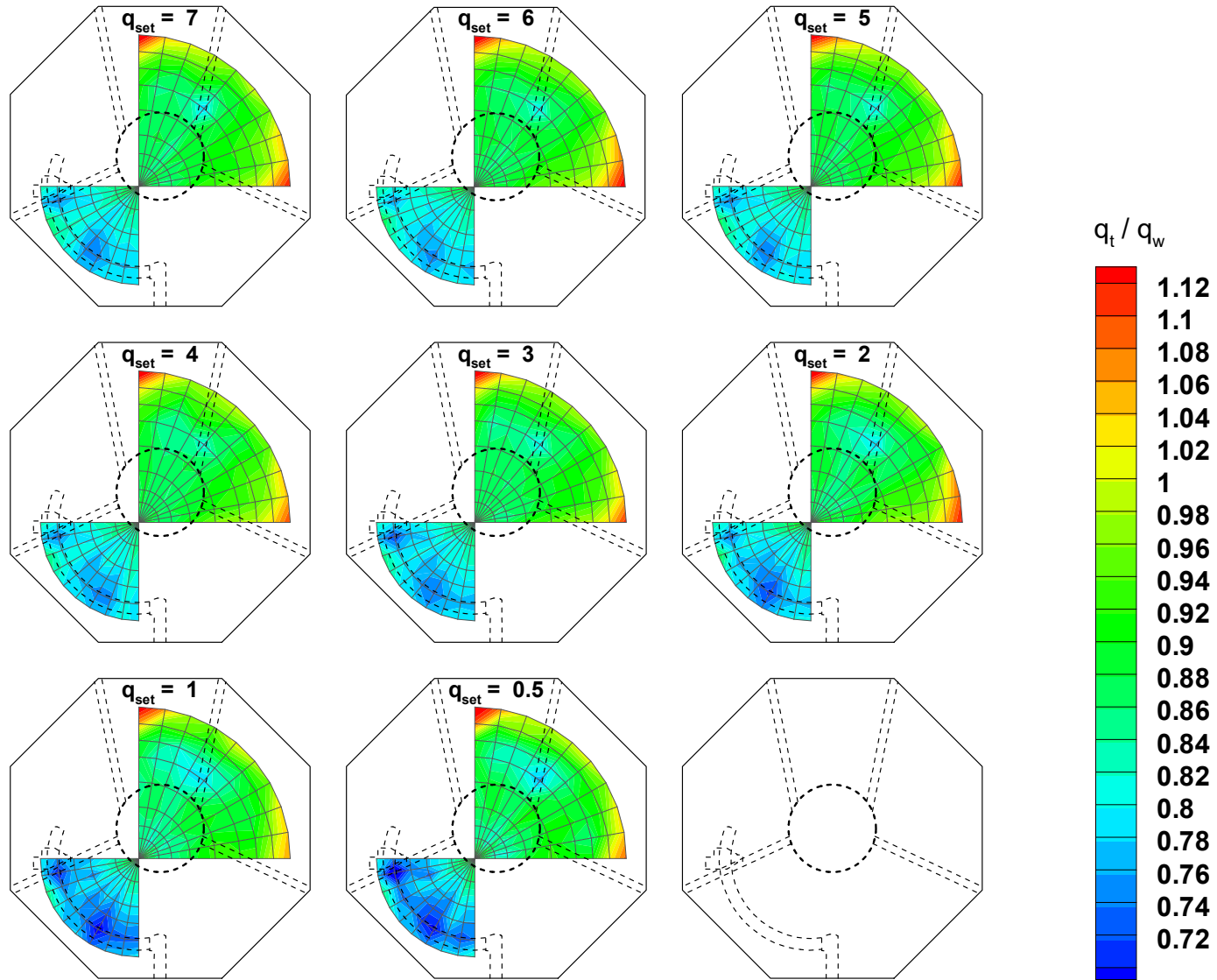


Figure 18 - Survey contour plots of q_t/q_w ratio for C-Strut yawed $+90^\circ$ and $\varepsilon = 0^\circ$ (looking upstream).

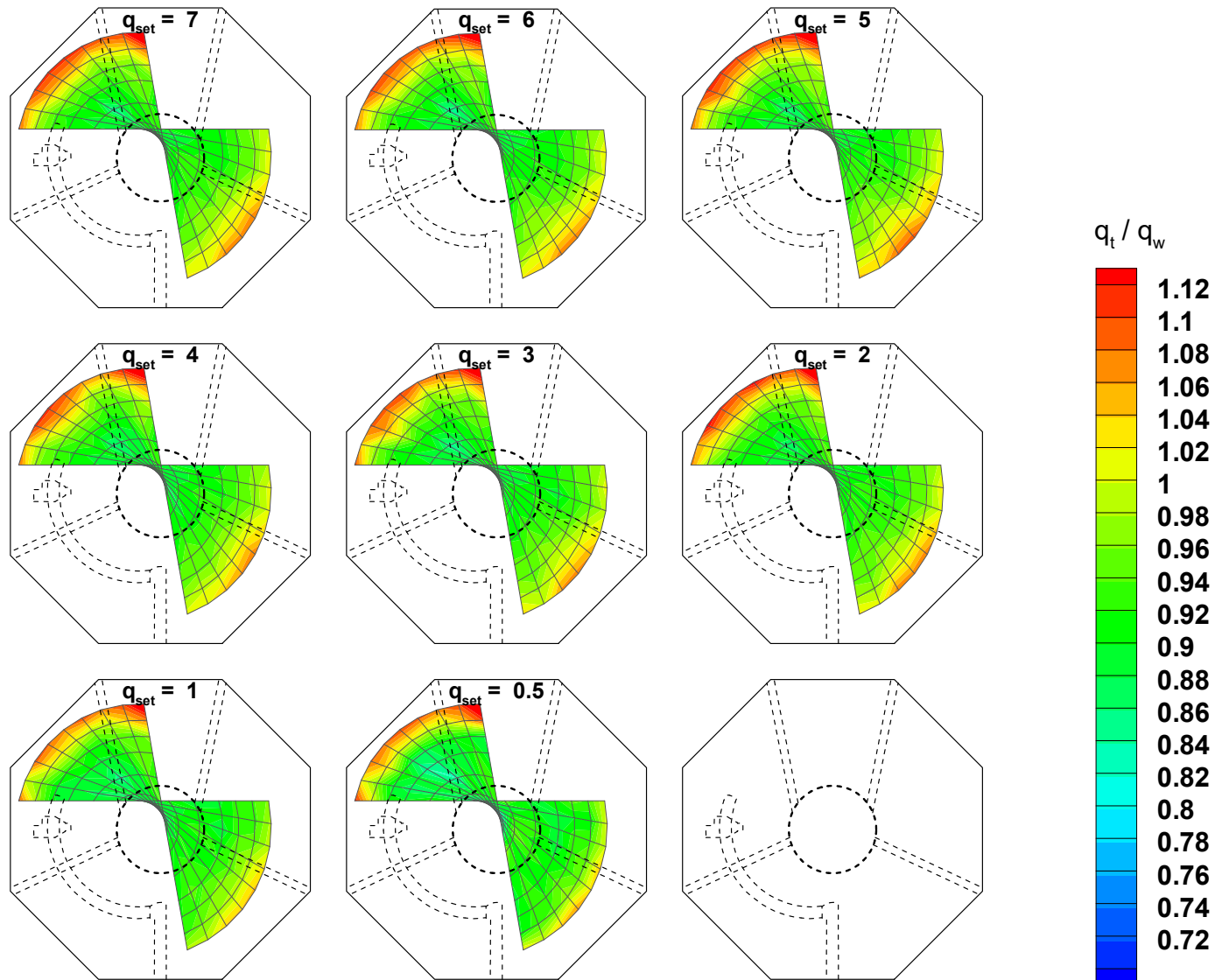


Figure 19 - Survey contour plots of q_t/q_w ratio for C-Strut yawed $+90^\circ$ and $\varepsilon = 80^\circ$ (looking upstream).

Acknowledgements

This work was made possible by Cathy Williams for creating the program used to record all the pressure data from the probes as well as Wes O'Neal's contribution in adjusting and operating the program as needed.

Summary and Future Work

A tunnel calibration factor is a vital element for wind tunnel testing to ensure the data recorded during testing accurately represents the flow seen in the test section. Improper use of this value could lead to skewed data and improper assumptions of results. This value should be determined for any wind tunnel on a regular basis to ensure continued accuracy of flow data, and in this case dynamic pressure readings. This paper also has shown a variety of correction factors and how to determine the appropriate one for use during testing. Using the provided formulas, any wind tunnel dynamic pressure reading can be calibrated using a pitot-static pressure probe rake.

In conjunction with a tunnel calibration, a hot wire test can be run to determine flow turbulence as well as a multiprobe, or windvane, test to determine flow angularity. The combination of these three tests can offer an encapsulating view of the overall flow of the tunnel and accuracy of the wall dynamic pressure probe. Future surveys would benefit from a rake that could complete the full phi sweep while the C-Strut is yawed 90°. Having a closer on-to-one comparison or pressure data at 0° and 90° C-strut yaw would better describe the impact on the regional flow caused by the model support equipment being broadside to the flow. Seeing as this C-Strut will be used in the future FDRF, an adaptation to the current test rig would be advantageous for data gathering.

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Appendix

Table A2 – Full survey pressure ratio values.

r	ϕ	x	y	q_p/q_w								
ft	deg	ft	ft	$q_s = 0.25$	$q_s = 0.5$	$q_s = 1.0$	$q_s = 2.0$	$q_s = 3.0$	$q_s = 4.0$	$q_s = 5.0$	$q_s = 6.0$	$q_s = 7.0$
5.000	0	5.000	-0.333	1.0088	0.9701	0.9668	0.9799	0.9806	0.9845	0.9852	0.9834	0.9749
4.333	0	4.333	-0.333	0.9653	0.9326	0.9159	0.9209	0.9238	0.9259	0.9255	0.9228	0.9182
3.667	0	3.667	-0.333	0.9851	0.9434	0.9099	0.9110	0.9094	0.9074	0.9046	0.9049	0.8950
3.000	0	3.000	-0.333	0.9673	0.9355	0.8986	0.8853	0.8830	0.8839	0.8802	0.8798	0.8686
2.000	0	2.000	-0.333	0.9132	0.8786	0.8600	0.8674	0.8645	0.8647	0.8628	0.8587	0.8535
1.000	0	1.000	-0.333	0.9011	0.8689	0.8494	0.8573	0.8520	0.8487	0.8451	0.8410	0.8333
0.250	0	0.250	-0.333	0.9152	0.8895	0.8618	0.8599	0.8545	0.8545	0.8513	0.8505	0.8446
-0.250	0	-0.250	-0.333	0.9194	0.8970	0.8781	0.8752	0.8727	0.8700	0.8677	0.8636	0.8538
-1.000	0	-1.000	-0.333	0.9124	0.8872	0.8643	0.8646	0.8629	0.8628	0.8607	0.8582	0.8491
-2.000	0	-2.000	-0.333	0.8951	0.8640	0.8391	0.8458	0.8469	0.8471	0.8462	0.8440	0.8372
-3.000	0	-3.000	-0.333	0.9088	0.8779	0.8516	0.8565	0.8528	0.8571	0.8560	0.8570	0.8506
-3.666	0	-3.666	-0.333	0.9485	0.9213	0.8985	0.8947	0.8911	0.8909	0.8884	0.8847	0.8779
-4.333	0	-4.333	-0.333	0.9546	0.9298	0.9124	0.9141	0.9130	0.9155	0.9110	0.9101	0.9012
-5.000	0	-5.000	-0.333	0.9612	0.9530	0.9526	0.9492	0.9641	0.9551	0.9513	0.9545	0.9452
5.000	10	4.924	0.535	1.0329	1.0277	0.9846	1.0058	1.0220	1.0228	1.0211	1.0319	1.0389
4.333	10	4.267	0.419	0.9759	0.9766	0.9248	0.9319	0.9428	0.9405	0.9321	0.9468	0.9445
3.667	10	3.611	0.303	0.9403	0.9452	0.9074	0.9154	0.9278	0.9180	0.9108	0.9257	0.9172
3.000	10	2.954	0.188	0.9395	0.9210	0.8942	0.8824	0.8963	0.8823	0.8808	0.9006	0.8817
2.000	10	1.970	0.014	0.9044	0.8843	0.8567	0.8631	0.8720	0.8634	0.8600	0.8763	0.8609
1.000	10	0.985	-0.160	0.8729	0.8518	0.8279	0.8359	0.8448	0.8379	0.8322	0.8417	0.8356
0.250	10	0.246	-0.290	0.9085	0.8886	0.8500	0.8541	0.8629	0.8570	0.8503	0.8603	0.8501
-0.250	10	-0.246	-0.377	0.9107	0.8970	0.8672	0.8741	0.8800	0.8710	0.8633	0.8734	0.8635
-1.000	10	-0.985	-0.507	0.9077	0.8842	0.8580	0.8591	0.8668	0.8591	0.8526	0.8621	0.8531
-2.000	10	-1.970	-0.681	0.8828	0.8760	0.8436	0.8476	0.8578	0.8463	0.8415	0.8468	0.8419
-3.000	10	-2.954	-0.854	0.9263	0.8762	0.8470	0.8774	0.8768	0.8693	0.8662	0.8798	0.8659
-3.666	10	-3.610	-0.970	0.9370	0.9250	0.8937	0.8979	0.9031	0.8977	0.8917	0.8985	0.8959

r	ϕ	x	y	q_p/q_w								
ft	deg	ft	ft	$q_s = 0.25$	$q_s = 0.5$	$q_s = 1.0$	$q_s = 2.0$	$q_s = 3.0$	$q_s = 4.0$	$q_s = 5.0$	$q_s = 6.0$	$q_s = 7.0$
-4.333	10	-4.267	-1.086	1.0016	0.9812	0.9703	0.9508	0.9796	0.9816	0.9806	0.9812	0.9818
-5.000	10	-4.924	-1.202	1.0645	1.0271	0.9934	1.0001	1.0215	0.9881	0.9944	1.0133	0.9872
5.000	20	4.698	1.377	1.0915	1.0811	1.0491	1.0287	1.0148	0.9999	1.0094	1.0190	1.0070
4.333	20	4.072	1.149	0.9445	0.9785	0.9440	0.9539	0.9442	0.9441	0.9393	0.9500	0.9448
3.667	20	3.446	0.921	0.9812	0.9783	0.9497	0.9543	0.9401	0.9364	0.9374	0.9382	0.9383
3.000	20	2.819	0.693	0.9329	0.9297	0.9197	0.9067	0.9065	0.8964	0.8932	0.8962	0.9031
2.000	20	1.879	0.351	0.8905	0.8866	0.8621	0.8848	0.8675	0.8689	0.8659	0.8631	0.8619
1.000	20	0.940	0.009	0.9089	0.8798	0.8584	0.8707	0.8518	0.8542	0.8517	0.8506	0.8468
0.250	20	0.235	-0.248	0.9196	0.8862	0.8535	0.8647	0.8444	0.8466	0.8442	0.8477	0.8438
-0.250	20	-0.235	-0.419	0.9155	0.8849	0.8685	0.8786	0.8607	0.8636	0.8594	0.8595	0.8566
-1.000	20	-0.940	-0.675	0.9210	0.8850	0.8670	0.8766	0.8568	0.8601	0.8574	0.8575	0.8547
-2.000	20	-1.879	-1.017	0.9180	0.8978	0.8737	0.8770	0.8609	0.8661	0.8603	0.8614	0.8605
-3.000	20	-2.819	-1.359	0.9669	0.9378	0.9273	0.9392	0.9192	0.9242	0.9194	0.9255	0.9197
-3.666	20	-3.445	-1.587	0.9333	0.9272	0.9004	0.9182	0.9069	0.9058	0.9078	0.9056	0.9092
-4.333	20	-4.072	-1.815	0.9740	0.9502	0.9316	0.9473	0.9315	0.9252	0.9266	0.9307	0.9307
-5.000	20	-4.698	-2.043	1.0029	0.9815	0.9606	0.9813	0.9631	0.9572	0.9597	0.9645	0.9638
5.000	30	4.330	2.167	1.0771	1.0674	1.0413	1.0569	1.0621	1.0771	1.0504	1.0534	1.0518
4.333	30	3.752	1.833	0.9775	0.9960	0.9913	0.9799	0.9990	1.0001	0.9775	0.9867	0.9900
3.667	30	3.175	1.500	0.9897	0.9746	0.9577	0.9554	0.9647	0.9689	0.9477	0.9567	0.9559
3.000	30	2.598	1.167	0.8897	0.9074	0.8903	0.8830	0.8927	0.8986	0.8763	0.8908	0.8860
2.000	30	1.732	0.667	0.9174	0.8955	0.8641	0.8812	0.8778	0.8940	0.8710	0.8756	0.8757
1.000	30	0.866	0.167	0.9103	0.8927	0.8548	0.8628	0.8636	0.8720	0.8495	0.8485	0.8501
0.250	30	0.217	-0.208	0.9068	0.8858	0.8516	0.8559	0.8554	0.8631	0.8426	0.8429	0.8440
-0.250	30	-0.217	-0.458	0.9059	0.8862	0.8549	0.8648	0.8643	0.8743	0.8512	0.8551	0.8546
-1.000	30	-0.866	-0.833	0.9169	0.8829	0.8579	0.8601	0.8616	0.8725	0.8494	0.8515	0.8513
-2.000	30	-1.732	-1.333	0.9173	0.9005	0.8682	0.8769	0.8768	0.8872	0.8614	0.8680	0.8674
-3.000	30	-2.598	-1.833	0.9415	0.9177	0.8842	0.8840	0.8814	0.8939	0.8672	0.8697	0.8713
-3.666	30	-3.175	-2.166	0.9160	0.9070	0.8818	0.8980	0.8910	0.9061	0.8745	0.8852	0.8782
-4.333	30	-3.752	-2.500	0.9116	0.9015	0.8662	0.9369	0.8863	0.9504	0.8770	0.8969	0.8798

r	ϕ	x	y	q_p/q_w								
ft	deg	ft	ft	$q_s = 0.25$	$q_s = 0.5$	$q_s = 1.0$	$q_s = 2.0$	$q_s = 3.0$	$q_s = 4.0$	$q_s = 5.0$	$q_s = 6.0$	$q_s = 7.0$
-5.000	30	-4.330	-2.833	1.0099	1.0020	0.9531	1.0160	0.9745	1.0347	0.9635	0.9880	0.9681
5.000	40	3.830	2.881	1.0486	1.0417	1.0394	1.0422	1.0558	1.0309	1.0391	1.0417	1.0315
4.333	40	3.319	2.452	0.9975	0.9884	0.9818	0.9849	1.0022	0.9805	0.9926	0.9921	0.9865
3.667	40	2.809	2.024	0.9728	0.9450	0.9389	0.9406	0.9579	0.9337	0.9402	0.9426	0.9372
3.000	40	2.298	1.595	0.9432	0.9248	0.9196	0.9095	0.9278	0.9077	0.9103	0.9113	0.9087
2.000	40	1.532	0.952	0.9381	0.9041	0.8881	0.8745	0.8836	0.8708	0.8701	0.8764	0.8694
1.000	40	0.766	0.309	0.8867	0.8578	0.8477	0.8430	0.8539	0.8390	0.8381	0.8460	0.8361
0.250	40	0.192	-0.173	0.9022	0.8806	0.8641	0.8526	0.8559	0.8432	0.8433	0.8500	0.8390
-0.250	40	-0.192	-0.494	0.9115	0.8766	0.8636	0.8516	0.8619	0.8508	0.8497	0.8561	0.8465
-1.000	40	-0.766	-0.976	0.9117	0.8802	0.8728	0.8552	0.8621	0.8468	0.8458	0.8515	0.8416
-2.000	40	-1.532	-1.619	0.9153	0.8852	0.8630	0.8557	0.8617	0.8501	0.8501	0.8562	0.8476
-3.000	40	-2.298	-2.262	0.9030	0.8774	0.8663	0.8648	0.8673	0.8548	0.8540	0.8575	0.8495
-3.666	40	-2.808	-2.690	0.8929	0.8716	0.8644	0.8767	0.8792	0.8427	0.8391	0.8454	0.8361
-4.333	40	-3.319	-3.119	0.9898	0.9495	0.9200	0.9407	0.9464	0.8998	0.9025	0.9054	0.8973
-5.000	40	-3.830	-3.547	1.0215	0.9854	0.9750	1.0012	1.0043	0.9701	0.9731	0.9769	0.9679
5.000	50	3.214	3.497	1.0813	1.0013	0.9880	1.0159	1.0189	1.0173	1.0057	1.0054	1.0107
4.333	50	2.785	2.986	1.0113	0.9638	0.9536	0.9756	0.9810	0.9812	0.9705	0.9665	0.9747
3.667	50	2.357	2.476	0.9734	0.9263	0.9142	0.9336	0.9415	0.9405	0.9290	0.9281	0.9336
3.000	50	1.928	1.965	0.9838	0.9144	0.8960	0.9063	0.9125	0.9099	0.8975	0.8965	0.9004
2.000	50	1.286	1.199	0.9287	0.8572	0.8396	0.8504	0.8515	0.8511	0.8408	0.8348	0.8418
1.000	50	0.643	0.433	0.9089	0.8685	0.8461	0.8558	0.8566	0.8543	0.8391	0.8371	0.8394
0.250	50	0.161	-0.142	0.8997	0.8615	0.8388	0.8478	0.8489	0.8457	0.8353	0.8374	0.8399
-0.250	50	-0.161	-0.525	0.9195	0.8660	0.8449	0.8464	0.8575	0.8547	0.8422	0.8416	0.8480
-1.000	50	-0.643	-1.099	0.9359	0.8807	0.8645	0.8709	0.8701	0.8660	0.8526	0.8528	0.8553
-2.000	50	-1.286	-1.865	0.9292	0.8727	0.8580	0.8602	0.8620	0.8575	0.8427	0.8428	0.8436
-3.000	50	-1.928	-2.631	0.9038	0.8569	0.8385	0.8393	0.8376	0.8306	0.8199	0.8193	0.8192
-3.666	50	-2.356	-3.142	0.9400	0.8900	0.8743	0.8801	0.8777	0.8757	0.8622	0.8628	0.8666
-4.333	50	-2.785	-3.653	0.9724	0.9177	0.8965	0.9164	0.9113	0.9107	0.8965	0.8965	0.8984
-5.000	50	-3.214	-4.164	1.0447	0.9901	0.9674	0.9892	0.9807	0.9794	0.9635	0.9688	0.9639

r	ϕ	x	y	q_p/q_w								
ft	deg	ft	ft	$q_s = 0.25$	$q_s = 0.5$	$q_s = 1.0$	$q_s = 2.0$	$q_s = 3.0$	$q_s = 4.0$	$q_s = 5.0$	$q_s = 6.0$	$q_s = 7.0$
5.000	60	2.500	3.997	1.0533	1.0062	0.9780	1.0031	1.0207	1.0086	0.9862	1.0046	1.0073
4.333	60	2.167	3.419	0.9859	0.9373	0.9267	0.9487	0.9659	0.9587	0.9414	0.9587	0.9615
3.667	60	1.833	2.842	0.9581	0.9095	0.8852	0.9081	0.9225	0.9185	0.9009	0.9198	0.9179
3.000	60	1.500	2.265	0.9230	0.8726	0.8576	0.8779	0.8937	0.8883	0.8727	0.8840	0.8845
2.000	60	1.000	1.399	0.9486	0.8936	0.8626	0.8680	0.8833	0.8656	0.8499	0.8620	0.8598
1.000	60	0.500	0.533	0.9280	0.8749	0.8466	0.8526	0.8641	0.8504	0.8332	0.8450	0.8427
0.250	60	0.125	-0.117	0.8888	0.8445	0.8197	0.8354	0.8476	0.8375	0.8213	0.8371	0.8361
-0.250	60	-0.125	-0.550	0.9166	0.8610	0.8367	0.8414	0.8575	0.8489	0.8326	0.8420	0.8442
-1.000	60	-0.500	-1.199	0.9515	0.8976	0.8676	0.8680	0.8776	0.8659	0.8475	0.8592	0.8549
-2.000	60	-1.000	-2.065	0.9368	0.8813	0.8433	0.8486	0.8548	0.8346	0.8192	0.8357	0.8339
-3.000	60	-1.500	-2.931	0.9101	0.8597	0.8339	0.8496	0.8505	0.8403	0.8257	0.8337	0.8345
-3.666	60	-1.833	-3.508	0.9295	0.8800	0.8563	0.8701	0.8709	0.8630	0.8467	0.8554	0.8586
-4.333	60	-2.167	-4.086	0.9895	0.9317	0.9007	0.9154	0.9188	0.9088	0.8945	0.8995	0.9073
-5.000	60	-2.500	-4.663	0.9808	0.9417	0.9279	0.9451	0.9463	0.9417	0.9232	0.9305	0.9360
5.000	70	1.710	4.365	0.9656	0.9530	0.9481	0.9635	0.9878	0.9760	0.9723	0.9770	0.9815
4.333	70	1.482	3.738	0.9265	0.8999	0.8825	0.9049	0.9216	0.9131	0.9093	0.9142	0.9201
3.667	70	1.254	3.112	0.9484	0.9095	0.8827	0.8952	0.9077	0.8981	0.8934	0.8979	0.9043
3.000	70	1.026	2.486	0.9281	0.8953	0.8768	0.8806	0.8863	0.8739	0.8718	0.8732	0.8790
2.000	70	0.684	1.546	0.9251	0.8888	0.8659	0.8747	0.8820	0.8702	0.8666	0.8665	0.8719
1.000	70	0.342	0.606	0.9136	0.8849	0.8620	0.8651	0.8704	0.8568	0.8527	0.8544	0.8586
0.250	70	0.086	-0.098	0.8781	0.8412	0.8165	0.8316	0.8406	0.8265	0.8264	0.8196	0.8283
-0.250	70	-0.086	-0.568	0.8893	0.8588	0.8384	0.8475	0.8571	0.8465	0.8424	0.8427	0.8490
-1.000	70	-0.342	-1.273	0.9289	0.8910	0.8718	0.8670	0.8728	0.8588	0.8545	0.8543	0.8550
-2.000	70	-0.684	-2.213	0.9130	0.8923	0.8651	0.8604	0.8695	0.8536	0.8500	0.8488	0.8516
-3.000	70	-1.026	-3.152	0.9242	0.8895	0.8727	0.8766	0.8836	0.8670	0.8620	0.8624	0.8672
-3.666	70	-1.254	-3.778	0.9150	0.8915	0.8786	0.8872	0.8925	0.8823	0.8788	0.8779	0.8824
-4.333	70	-1.482	-4.405	0.9256	0.9046	0.8804	0.9027	0.9072	0.8945	0.8915	0.8890	0.8932
-5.000	70	-1.710	-5.032	0.9937	0.9883	0.9625	0.9749	0.9792	0.9614	0.9622	0.9622	0.9689
5.000	80	0.868	4.591	0.9190	0.9009	0.8881	0.9011	0.9333	0.9407	0.9241	0.9317	0.9361

r	ϕ	x	y	q_p/q_w								
ft	deg	ft	ft	$q_s = 0.25$	$q_s = 0.5$	$q_s = 1.0$	$q_s = 2.0$	$q_s = 3.0$	$q_s = 4.0$	$q_s = 5.0$	$q_s = 6.0$	$q_s = 7.0$
4.333	80	0.752	3.934	0.9744	0.9169	0.9040	0.8956	0.9170	0.9204	0.9053	0.9061	0.9144
3.667	80	0.637	3.278	0.9060	0.8608	0.8497	0.8582	0.8815	0.8837	0.8690	0.8745	0.8758
3.000	80	0.521	2.621	0.8998	0.8365	0.8329	0.8418	0.8604	0.8608	0.8507	0.8530	0.8558
2.000	80	0.347	1.636	0.9432	0.8662	0.8606	0.8611	0.8763	0.8700	0.8612	0.8598	0.8636
1.000	80	0.174	0.651	0.9030	0.8559	0.8434	0.8483	0.8646	0.8596	0.8505	0.8514	0.8536
0.250	80	0.043	-0.087	0.8937	0.8346	0.8080	0.8255	0.8326	0.8341	0.8214	0.8248	0.8238
-0.250	80	-0.043	-0.580	0.9006	0.8449	0.8334	0.8394	0.8578	0.8539	0.8428	0.8441	0.8465
-1.000	80	-0.174	-1.318	0.9252	0.8654	0.8554	0.8547	0.8671	0.8607	0.8493	0.8503	0.8498
-2.000	80	-0.347	-2.303	0.9096	0.8653	0.8477	0.8552	0.8558	0.8537	0.8421	0.8452	0.8495
-3.000	80	-0.521	-3.288	0.9198	0.8791	0.8716	0.8788	0.8947	0.8875	0.8844	0.8887	0.8895
-3.666	80	-0.637	-3.944	0.9862	0.9467	0.9304	0.9342	0.9467	0.9345	0.9294	0.9348	0.9365
-4.333	80	-0.752	-4.601	1.0093	0.9496	0.9385	0.9514	0.9575	0.9480	0.9500	0.9567	0.9584
-5.000	80	-0.868	-5.257	1.1256	1.0829	1.0645	1.0360	1.0519	1.0633	1.0639	1.0731	1.0730
5.000	90	0.000	4.667	0.9635	0.9499	0.9340	0.9167	0.9335	0.9090	0.9131	0.9106	0.9174
4.333	90	0.000	4.000	0.9515	0.9109	0.8789	0.8891	0.8928	0.8723	0.8697	0.8700	0.8701
3.667	90	0.000	3.333	0.8985	0.8853	0.8802	0.8705	0.8808	0.8677	0.8663	0.8652	0.8645
3.000	90	0.000	2.667	0.8790	0.8502	0.8412	0.8492	0.8559	0.8507	0.8562	0.8521	0.8563
2.000	90	0.000	1.667	0.8995	0.8662	0.8486	0.8345	0.8463	0.8347	0.8362	0.8362	0.8376
1.000	90	0.000	0.667	0.9289	0.8919	0.8677	0.8467	0.8614	0.8446	0.8444	0.8422	0.8446
0.250	90	0.000	-0.083	0.8894	0.8406	0.8198	0.8239	0.8310	0.8152	0.8199	0.8233	0.8263
-0.250	90	0.000	-0.583	0.8864	0.8629	0.8458	0.8397	0.8536	0.8408	0.8387	0.8396	0.8422
-1.000	90	0.000	-1.333	0.9162	0.8813	0.8643	0.8493	0.8596	0.8458	0.8474	0.8459	0.8475
-2.000	90	0.000	-2.333	0.8890	0.8575	0.8477	0.8388	0.8508	0.8333	0.8373	0.8373	0.8398
-3.000	90	0.000	-3.333	0.8859	0.8515	0.8405	0.8339	0.8475	0.8346	0.8352	0.8330	0.8375
-3.666	90	0.000	-3.999	0.8869	0.8577	0.8491	0.8425	0.8638	0.8497	0.8504	0.8541	0.8529
-4.333	90	0.000	-4.666	0.9610	0.9325	0.9123	0.9027	0.9064	0.8967	0.8988	0.9032	0.8906
-5.000	90	0.000	-5.333	1.0092	0.9794	0.9705	0.9501	0.9782	0.9631	0.9537	0.9521	0.9729
5.000	100	-0.868	4.591	0.9891	0.9287	0.9136	0.9325	0.9599	0.9343	0.9366	0.9412	0.9371
4.333	100	-0.752	3.934	0.9495	0.8862	0.8832	0.8968	0.9157	0.8985	0.9161	0.9122	0.9089

r	ϕ	x	y	q_p/q_w								
ft	deg	ft	ft	$q_s = 0.25$	$q_s = 0.5$	$q_s = 1.0$	$q_s = 2.0$	$q_s = 3.0$	$q_s = 4.0$	$q_s = 5.0$	$q_s = 6.0$	$q_s = 7.0$
3.667	100	-0.637	3.278	0.8921	0.8447	0.8479	0.8731	0.8982	0.8837	0.8937	0.8999	0.8967
3.000	100	-0.521	2.621	0.8942	0.8330	0.8527	0.8711	0.8874	0.8756	0.8749	0.8756	0.8844
2.000	100	-0.347	1.636	0.9370	0.8635	0.8597	0.8714	0.8804	0.8608	0.8595	0.8613	0.8632
1.000	100	-0.174	0.651	0.9342	0.8642	0.8651	0.8759	0.8871	0.8673	0.8656	0.8661	0.8678
0.250	100	-0.043	-0.087	0.8926	0.8271	0.8264	0.8363	0.8495	0.8316	0.8305	0.8284	0.8316
-0.250	100	0.043	-0.580	0.8842	0.8271	0.8384	0.8465	0.8613	0.8427	0.8400	0.8397	0.8421
-1.000	100	0.174	-1.318	0.9068	0.8418	0.8452	0.8557	0.8634	0.8474	0.8450	0.8435	0.8448
-2.000	100	0.347	-2.303	0.8883	0.8247	0.8306	0.8405	0.8570	0.8358	0.8381	0.8393	0.8412
-3.000	100	0.521	-3.288	0.8710	0.8197	0.8222	0.8321	0.8429	0.8289	0.8272	0.8296	0.8329
-3.666	100	0.637	-3.944	0.8311	0.7934	0.8115	0.8260	0.8374	0.8328	0.8213	0.8236	0.8269
-4.333	100	0.752	-4.601	0.9648	0.8970	0.9229	0.9294	0.9460	0.9287	0.9296	0.9285	0.9290
-5.000	100	0.868	-5.257	0.9983	0.9284	0.9615	0.9841	0.9984	0.9819	0.9842	0.9827	0.9837
5.000	110	-1.710	4.365	1.0002	0.9987	0.9923	0.9927	1.0083	1.0119	1.0018	1.0109	0.9912
4.333	110	-1.482	3.738	0.9635	0.9363	0.9300	0.9463	0.9560	0.9766	0.9613	0.9688	0.9549
3.667	110	-1.254	3.112	0.9482	0.9364	0.9308	0.9225	0.9318	0.9424	0.9312	0.9398	0.9335
3.000	110	-1.026	2.486	0.9516	0.9149	0.9132	0.8911	0.8948	0.9037	0.8943	0.9062	0.8967
2.000	110	-0.684	1.546	0.9663	0.9183	0.8981	0.8805	0.8827	0.8823	0.8718	0.8773	0.8664
1.000	110	-0.342	0.606	0.9110	0.8767	0.8570	0.8541	0.8639	0.8620	0.8497	0.8580	0.8465
0.250	110	-0.086	-0.098	0.9019	0.8518	0.8367	0.8308	0.8390	0.8400	0.8306	0.8372	0.8259
-0.250	110	0.086	-0.568	0.8762	0.8573	0.8400	0.8311	0.8415	0.8423	0.8307	0.8383	0.8266
-1.000	110	0.342	-1.273	0.9095	0.8714	0.8529	0.8420	0.8492	0.8501	0.8391	0.8463	0.8357
-2.000	110	0.684	-2.213	0.8974	0.8607	0.8410	0.8339	0.8429	0.8417	0.8321	0.8398	0.8281
-3.000	110	1.026	-3.152	0.8772	0.8409	0.8194	0.8014	0.8151	0.8168	0.8057	0.8045	0.8009
-3.666	110	1.254	-3.778	0.8882	0.8589	0.8509	0.8393	0.8530	0.8529	0.8427	0.8465	0.8435
-4.333	110	1.482	-4.405	0.9452	0.9096	0.9009	0.8990	0.9148	0.9125	0.9041	0.9076	0.9042
-5.000	110	1.710	-5.032	0.9840	0.9511	0.9448	0.9396	0.9590	0.9557	0.9528	0.9534	0.9477
5.000	120	-2.500	3.997	1.0293	0.9623	0.9778	0.9658	0.9825	0.9847	0.9865	1.0089	0.9784
4.333	120	-2.167	3.419	1.0164	0.9537	0.9625	0.9444	0.9554	0.9641	0.9603	0.9740	0.9496
3.667	120	-1.833	2.842	0.9964	0.9444	0.9415	0.9287	0.9269	0.9351	0.9372	0.9564	0.9274

r	ϕ	x	y	q_p/q_w								
ft	deg	ft	ft	$q_s = 0.25$	$q_s = 0.5$	$q_s = 1.0$	$q_s = 2.0$	$q_s = 3.0$	$q_s = 4.0$	$q_s = 5.0$	$q_s = 6.0$	$q_s = 7.0$
3.000	120	-1.500	2.265	0.9777	0.9176	0.9239	0.8958	0.8928	0.8910	0.8926	0.9207	0.8850
2.000	120	-1.000	1.399	0.9550	0.8964	0.8845	0.8555	0.8624	0.8720	0.8695	0.8790	0.8603
1.000	120	-0.500	0.533	0.9397	0.8833	0.8729	0.8519	0.8553	0.8663	0.8667	0.8749	0.8584
0.250	120	-0.125	-0.117	0.9026	0.8577	0.8549	0.8339	0.8377	0.8457	0.8446	0.8533	0.8380
-0.250	120	0.125	-0.550	0.8878	0.8437	0.8370	0.8229	0.8318	0.8457	0.8380	0.8484	0.8324
-1.000	120	0.500	-1.199	0.8986	0.8619	0.8503	0.8248	0.8298	0.8376	0.8304	0.8381	0.8246
-2.000	120	1.000	-2.065	0.9018	0.8603	0.8499	0.8307	0.8357	0.8453	0.8364	0.8468	0.8293
-3.000	120	1.500	-2.931	0.8844	0.8428	0.8255	0.8064	0.8120	0.8233	0.8224	0.8315	0.8159
-3.666	120	1.833	-3.508	0.8926	0.8535	0.8515	0.8416	0.8454	0.8570	0.8525	0.8607	0.8489
-4.333	120	2.167	-4.086	0.9531	0.9132	0.9112	0.9001	0.9032	0.9191	0.9109	0.9208	0.9127
-5.000	120	2.500	-4.663	0.9640	0.9330	0.9399	0.9303	0.9376	0.9488	0.9447	0.9544	0.9404
5.000	130	-3.214	3.497	1.0444	1.0246	0.9907	0.9930	0.9971	1.0034	0.9918	0.9958	0.9935
4.333	130	-2.785	2.986	0.9720	0.9449	0.9225	0.9381	0.9342	0.9387	0.9276	0.9386	0.9274
3.667	130	-2.357	2.476	0.9577	0.9255	0.9030	0.9170	0.9123	0.9165	0.9003	0.9062	0.9027
3.000	130	-1.928	1.965	0.9690	0.9157	0.8938	0.9028	0.8906	0.8959	0.8845	0.8952	0.8853
2.000	130	-1.286	1.199	0.8882	0.8339	0.8130	0.8229	0.8175	0.8206	0.8096	0.8242	0.8161
1.000	130	-0.643	0.433	0.9159	0.8966	0.8692	0.8753	0.8728	0.8697	0.8570	0.8639	0.8540
0.250	130	-0.161	-0.142	0.8876	0.8841	0.8558	0.8614	0.8632	0.8532	0.8416	0.8450	0.8369
-0.250	130	0.161	-0.525	0.8658	0.8516	0.8275	0.8387	0.8401	0.8423	0.8280	0.8291	0.8234
-1.000	130	0.643	-1.099	0.8843	0.8747	0.8457	0.8465	0.8450	0.8428	0.8260	0.8278	0.8207
-2.000	130	1.286	-1.865	0.8797	0.8713	0.8419	0.8541	0.8555	0.8571	0.8443	0.8465	0.8413
-3.000	130	1.928	-2.631	0.8020	0.8007	0.7678	0.7841	0.7871	0.7810	0.7715	0.7706	0.7739
-3.666	130	2.356	-3.142	0.8441	0.8458	0.8242	0.8392	0.8404	0.8413	0.8322	0.8317	0.8321
-4.333	130	2.785	-3.653	0.9425	0.9235	0.8949	0.9070	0.9052	0.9053	0.8907	0.8953	0.8875
-5.000	130	3.214	-4.164	1.0284	1.0206	0.9630	0.9671	0.9604	0.9642	0.9456	0.9493	0.9357
5.000	140	-3.830	2.881	0.9791	0.9633	0.9813	0.9990	0.9971	1.0136	0.9986	0.9978	1.0022
4.333	140	-3.319	2.452	1.0218	0.9823	0.9689	0.9815	0.9755	0.9939	0.9826	0.9804	0.9769
3.667	140	-2.809	2.024	0.9746	0.9206	0.9034	0.9248	0.9160	0.9294	0.9245	0.9188	0.9212
3.000	140	-2.298	1.595	0.9308	0.8871	0.8831	0.8923	0.8869	0.8993	0.8866	0.8877	0.8886

r	ϕ	x	y	q_p/q_w								
ft	deg	ft	ft	$q_s = 0.25$	$q_s = 0.5$	$q_s = 1.0$	$q_s = 2.0$	$q_s = 3.0$	$q_s = 4.0$	$q_s = 5.0$	$q_s = 6.0$	$q_s = 7.0$
2.000	140	-1.532	0.952	0.9343	0.8894	0.8743	0.8786	0.8734	0.8862	0.8703	0.8681	0.8699
1.000	140	-0.766	0.309	0.9045	0.8603	0.8579	0.8687	0.8575	0.8705	0.8563	0.8585	0.8599
0.250	140	-0.192	-0.173	0.9197	0.8890	0.8755	0.8780	0.8729	0.8745	0.8616	0.8603	0.8587
-0.250	140	0.192	-0.494	0.8820	0.8393	0.8301	0.8436	0.8405	0.8468	0.8346	0.8354	0.8372
-1.000	140	0.766	-0.976	0.9066	0.8641	0.8561	0.8653	0.8550	0.8628	0.8511	0.8518	0.8520
-2.000	140	1.532	-1.619	0.8988	0.8586	0.8515	0.8618	0.8546	0.8624	0.8496	0.8510	0.8500
-3.000	140	2.298	-2.262	0.9171	0.8729	0.8670	0.8768	0.8682	0.8784	0.8673	0.8678	0.8687
-3.666	140	2.808	-2.690	0.8939	0.8521	0.8512	0.8498	0.8463	0.8517	0.8390	0.8410	0.8386
-4.333	140	3.319	-3.119	0.9584	0.9095	0.8962	0.8995	0.8895	0.8898	0.8804	0.8828	0.8846
-5.000	140	3.830	-3.547	1.0268	0.9845	0.9708	0.9862	0.9723	0.9837	0.9705	0.9660	0.9687
5.000	150	-4.330	2.167	1.0401	1.0216	1.0125	1.0201	1.0269	1.0271	1.0279	1.0224	1.0206
4.333	150	-3.752	1.833	0.9857	0.9856	0.9638	0.9672	0.9623	0.9681	0.9712	0.9756	0.9551
3.667	150	-3.175	1.500	0.9619	0.9462	0.9184	0.9277	0.9283	0.9314	0.9294	0.9266	0.9210
3.000	150	-2.598	1.167	0.8792	0.8462	0.8376	0.8574	0.8524	0.8583	0.8576	0.8506	0.8461
2.000	150	-1.732	0.667	0.9061	0.8808	0.8590	0.8663	0.8645	0.8680	0.8670	0.8618	0.8575
1.000	150	-0.866	0.167	0.9069	0.8833	0.8619	0.8733	0.8705	0.8748	0.8690	0.8640	0.8578
0.250	150	-0.217	-0.208	0.9230	0.8978	0.8712	0.8785	0.8739	0.8729	0.8678	0.8614	0.8565
-0.250	150	0.217	-0.458	0.8852	0.8525	0.8292	0.8402	0.8397	0.8422	0.8398	0.8342	0.8313
-1.000	150	0.866	-0.833	0.8995	0.8685	0.8491	0.8561	0.8516	0.8550	0.8540	0.8488	0.8450
-2.000	150	1.732	-1.333	0.9040	0.8757	0.8538	0.8620	0.8582	0.8624	0.8617	0.8565	0.8531
-3.000	150	2.598	-1.833	0.9405	0.9081	0.8843	0.8904	0.8840	0.8853	0.8850	0.8802	0.8765
-3.666	150	3.175	-2.166	0.9221	0.8909	0.8747	0.8746	0.8751	0.8714	0.8726	0.8684	0.8652
-4.333	150	3.752	-2.500	0.8526	0.8381	0.8198	0.8379	0.8460	0.8389	0.8408	0.8368	0.8344
-5.000	150	4.330	-2.833	0.9663	0.9576	0.9358	0.9458	0.9444	0.9493	0.9478	0.9380	0.9345
5.000	160	-4.698	1.377	1.0312	0.9944	0.9597	0.9585	0.9803	0.9693	0.9689	0.9777	0.9694
4.333	160	-4.072	1.149	0.9094	0.8776	0.8672	0.8819	0.8850	0.8961	0.9048	0.9116	0.9076
3.667	160	-3.446	0.921	0.9762	0.9350	0.9023	0.9106	0.9117	0.9138	0.9123	0.9201	0.9165
3.000	160	-2.819	0.693	0.9078	0.8741	0.8605	0.8645	0.8634	0.8707	0.8713	0.8723	0.8760
2.000	160	-1.879	0.351	0.9226	0.8710	0.8693	0.8651	0.8591	0.8524	0.8634	0.8637	0.8555

r	ϕ	x	y	q_p/q_w								
ft	deg	ft	ft	$q_s = 0.25$	$q_s = 0.5$	$q_s = 1.0$	$q_s = 2.0$	$q_s = 3.0$	$q_s = 4.0$	$q_s = 5.0$	$q_s = 6.0$	$q_s = 7.0$
1.000	160	-0.940	0.009	0.9355	0.8873	0.8676	0.8661	0.8646	0.8607	0.8657	0.8656	0.8612
0.250	160	-0.235	-0.248	0.9358	0.8986	0.8751	0.8747	0.8704	0.8603	0.8692	0.8693	0.8630
-0.250	160	0.235	-0.419	0.8935	0.8596	0.8414	0.8382	0.8433	0.8376	0.8453	0.8478	0.8422
-1.000	160	0.940	-0.675	0.8945	0.8556	0.8426	0.8434	0.8411	0.8373	0.8457	0.8441	0.8413
-2.000	160	1.879	-1.017	0.8937	0.8691	0.8593	0.8589	0.8596	0.8507	0.8608	0.8639	0.8576
-3.000	160	2.819	-1.359	0.9383	0.8910	0.8794	0.8803	0.8790	0.8729	0.8787	0.8802	0.8763
-3.666	160	3.445	-1.587	0.9425	0.8935	0.8799	0.8783	0.8770	0.8759	0.8777	0.8791	0.8763
-4.333	160	4.072	-1.815	1.0123	0.9477	0.9228	0.9261	0.9261	0.9240	0.9318	0.9328	0.9280
-5.000	160	4.698	-2.043	0.9811	0.9311	0.9269	0.9325	0.9414	0.9367	0.9450	0.9439	0.9472
5.000	170	-4.924	0.535	0.9950	0.9919	0.9485	0.9840	0.9747	0.9977	0.9954	0.9924	0.9988
4.333	170	-4.267	0.419	0.9741	0.9416	0.9048	0.9278	0.9204	0.9428	0.9398	0.9366	0.9412
3.667	170	-3.611	0.303	0.9496	0.8990	0.8743	0.8942	0.8877	0.9035	0.8926	0.8879	0.8901
3.000	170	-2.954	0.188	0.9304	0.8856	0.8404	0.8540	0.8468	0.8614	0.8527	0.8513	0.8540
2.000	170	-1.970	0.014	0.9407	0.8872	0.8363	0.8500	0.8437	0.8575	0.8470	0.8438	0.8509
1.000	170	-0.985	-0.160	0.9532	0.9027	0.8654	0.8814	0.8743	0.8861	0.8713	0.8686	0.8775
0.250	170	-0.246	-0.290	0.9572	0.9107	0.8723	0.8798	0.8697	0.8791	0.8679	0.8624	0.8718
-0.250	170	0.246	-0.377	0.9225	0.8784	0.8490	0.8562	0.8494	0.8630	0.8511	0.8489	0.8552
-1.000	170	0.985	-0.507	0.9229	0.8860	0.8538	0.8593	0.8484	0.8626	0.8488	0.8453	0.8545
-2.000	170	1.970	-0.681	0.9028	0.8670	0.8262	0.8544	0.8481	0.8609	0.8511	0.8467	0.8567
-3.000	170	2.954	-0.854	0.9704	0.9194	0.8742	0.8919	0.8787	0.8990	0.8803	0.8764	0.8934
-3.666	170	3.610	-0.970	0.9627	0.9413	0.9029	0.9175	0.9137	0.9353	0.9200	0.9163	0.9296
-4.333	170	4.267	-1.086	0.9957	0.9461	0.9154	0.9369	0.9336	0.9521	0.9384	0.9350	0.9484
-5.000	170	4.924	-1.202	1.0623	0.9935	0.9522	0.9881	0.9817	1.0061	0.9908	0.9860	1.0016
5.000	180	-5.000	-0.333	0.9798	0.9347	0.9307	0.9684	0.9633	0.9652	0.9581	0.9612	0.9651
4.333	180	-4.333	-0.333	0.9636	0.9044	0.8994	0.9202	0.9195	0.9239	0.9185	0.9125	0.9166
3.667	180	-3.667	-0.333	0.9875	0.9107	0.8951	0.9048	0.9010	0.9042	0.8972	0.8910	0.8895
3.000	180	-3.000	-0.333	0.9442	0.8689	0.8567	0.8637	0.8615	0.8693	0.8671	0.8646	0.8610
2.000	180	-2.000	-0.333	0.9259	0.8490	0.8323	0.8485	0.8464	0.8545	0.8498	0.8453	0.8447
1.000	180	-1.000	-0.333	0.9429	0.8748	0.8607	0.8748	0.8691	0.8727	0.8672	0.8634	0.8620

r	ϕ	x	y	q_p/q_w								
ft	deg	ft	ft	$q_s = 0.25$	$q_s = 0.5$	$q_s = 1.0$	$q_s = 2.0$	$q_s = 3.0$	$q_s = 4.0$	$q_s = 5.0$	$q_s = 6.0$	$q_s = 7.0$
0.250	180	-0.250	-0.333	0.9554	0.8849	0.8685	0.8781	0.8713	0.8751	0.8666	0.8630	0.8609
-0.250	180	0.250	-0.333	0.9244	0.8601	0.8423	0.8578	0.8566	0.8615	0.8550	0.8498	0.8486
-1.000	180	1.000	-0.333	0.9217	0.8627	0.8531	0.8618	0.8506	0.8549	0.8486	0.8428	0.8430
-2.000	180	2.000	-0.333	0.9318	0.8638	0.8592	0.8720	0.8642	0.8720	0.8674	0.8624	0.8631
-3.000	180	3.000	-0.333	0.9927	0.9090	0.8865	0.8929	0.8848	0.8896	0.8843	0.8765	0.8810
-3.666	180	3.666	-0.333	1.0006	0.9143	0.9022	0.9061	0.9059	0.9079	0.9043	0.8969	0.9004
-4.333	180	4.333	-0.333	1.0202	0.9313	0.9212	0.9320	0.9258	0.9378	0.9379	0.9273	0.9323
-5.000	180	5.000	-0.333	1.0368	0.9621	0.9660	0.9938	0.9842	0.9968	0.9946	0.9906	0.9917

Table A2 – Area averaged pressure survey values.

r , ft	q_{set} , psf	q_t , psf	q_t std, psf	q_p , psf	q_p std, psf
5.000	7.00	7.0758	0.0279	6.3327	0.0157
	6.00	6.0770	0.0231	5.4544	0.0179
	5.00	5.1340	0.0182	4.5920	0.0109
	4.00	4.1834	0.0151	3.7684	0.0110
	3.00	3.1721	0.0140	2.8615	0.0075
	2.00	2.1462	0.0109	1.9291	0.0052
	1.00	1.1074	0.0046	0.9880	0.0026
	0.50	0.5983	0.0030	0.5440	0.0013
	0.25	0.3331	0.0020	0.3149	0.0008
4.333	7.00	7.0758	0.0279	6.1974	0.0170
	6.00	6.0770	0.0231	5.3377	0.0186
	5.00	5.1340	0.0182	4.4944	0.0117
	4.00	4.1834	0.0151	3.6890	0.0124
	3.00	3.1721	0.0140	2.8020	0.0080
	2.00	2.1462	0.0109	1.8899	0.0055
	1.00	1.1074	0.0046	0.9693	0.0028
	0.50	0.5983	0.0030	0.5340	0.0014
	0.25	0.3331	0.0020	0.3097	0.0009
3.667	7.00	7.0758	0.0279	6.1051	0.0193
	6.00	6.0770	0.0231	5.2585	0.0199
	5.00	5.1340	0.0182	4.4283	0.0130
	4.00	4.1834	0.0151	3.6351	0.0147
	3.00	3.1721	0.0140	2.7622	0.0089
	2.00	2.1462	0.0109	1.8638	0.0062
	1.00	1.1074	0.0046	0.9574	0.0032
	0.50	0.5983	0.0030	0.5277	0.0016
	0.25	0.3331	0.0020	0.3066	0.0010
3.000	7.00	7.0758	0.0279	6.0481	0.0232
	6.00	6.0770	0.0231	5.2107	0.0224
	5.00	5.1340	0.0182	4.3892	0.0155
	4.00	4.1834	0.0151	3.6035	0.0186
	3.00	3.1721	0.0140	2.7390	0.0106
	2.00	2.1462	0.0109	1.8489	0.0074
	1.00	1.1074	0.0046	0.9505	0.0038
	0.50	0.5983	0.0030	0.5245	0.0019
	0.25	0.3331	0.0020	0.3053	0.0012
2.000	7.00	7.0758	0.0279	6.0093	0.0287
	6.00	6.0770	0.0231	5.1789	0.0243
	5.00	5.1340	0.0182	4.3647	0.0185
	4.00	4.1834	0.0151	3.5855	0.0245
	3.00	3.1721	0.0140	2.7264	0.0127

	2.00	2.1462	0.0109	1.8407	0.0088
	1.00	1.1074	0.0046	0.9469	0.0045
	0.50	0.5983	0.0030	0.5231	0.0023
	0.25	0.3331	0.0020	0.3044	0.0015
1.000	7.00	7.0758	0.0279	5.9850	0.0303
	6.00	6.0770	0.0231	5.1579	0.0246
	5.00	5.1340	0.0182	4.3477	0.0199
	4.00	4.1834	0.0151	3.5725	0.0248
	3.00	3.1721	0.0140	2.7168	0.0136
	2.00	2.1462	0.0109	1.8332	0.0092
	1.00	1.1074	0.0046	0.9426	0.0048
	0.50	0.5983	0.0030	0.5209	0.0026
	0.25	0.3331	0.0020	0.3028	0.0017