THE DAYTON T. BROWN, INC. WINDBLAST TEST FACILITY PRESENTATION TO SAFE EUROPE SYMPOSIUM 01 APRIL 2014

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ABSTRACT

Aircraft emergency egress during flight generates substantial loads on the aircrew member, personnel equipment, and aircraft components. These aerodynamic forces can compromise occupant safety during the ejection scenario. For fifty years, Dayton T. Brown, Inc. has been providing windblast testing services to evaluate safety for the aviator during aircraft emergency egress.

During the summer of 1999, an Enhanced Windblast Test Facility was designed and constructed at Dayton T. Brown, Inc. to replace the original facility which was built in the early 1960s. The centerpiece of the facility is a rectangular nozzle 3 feet wide and 5 feet high. The expanded flow field of the new nozzle generates a more realistic emergency egress environment and permits the testing of products of a larger aerodynamic profile. The facility also incorporated a redesigned symmetrically distributed air delivery system. This improvement produces a more uniform airflow across the nozzle. The Enhanced Windblast Test Facility at Dayton T. Brown, Inc. can accommodate all personnel equipment and aircraft escape systems to a peak design velocity of 700 Knots Equivalent Airspeed (KEAS).

This paper provides an overview of this facilities design, discusses the performance characteristics of the major assemblies, and presents operational velocity profile survey results accomplished by Wright-Patterson AFB and Dayton T. Brown, Inc.

Sebastian R. Grasso, P.E. the originator of this presentation and former staff member of Dayton T. Brown, Inc. continues to collaborate with DTB on engineering projects from time to time.

INTRODUCTION

- Test Facility Description
- Main Air Flow and Control Valves
- Air Supply and Storage
- Plenum and Nozzle
- Automated Control and Data Acquisition Systems
- Velocity Profile and Uniformity Performance Verification

FACILITY OVERVIEW

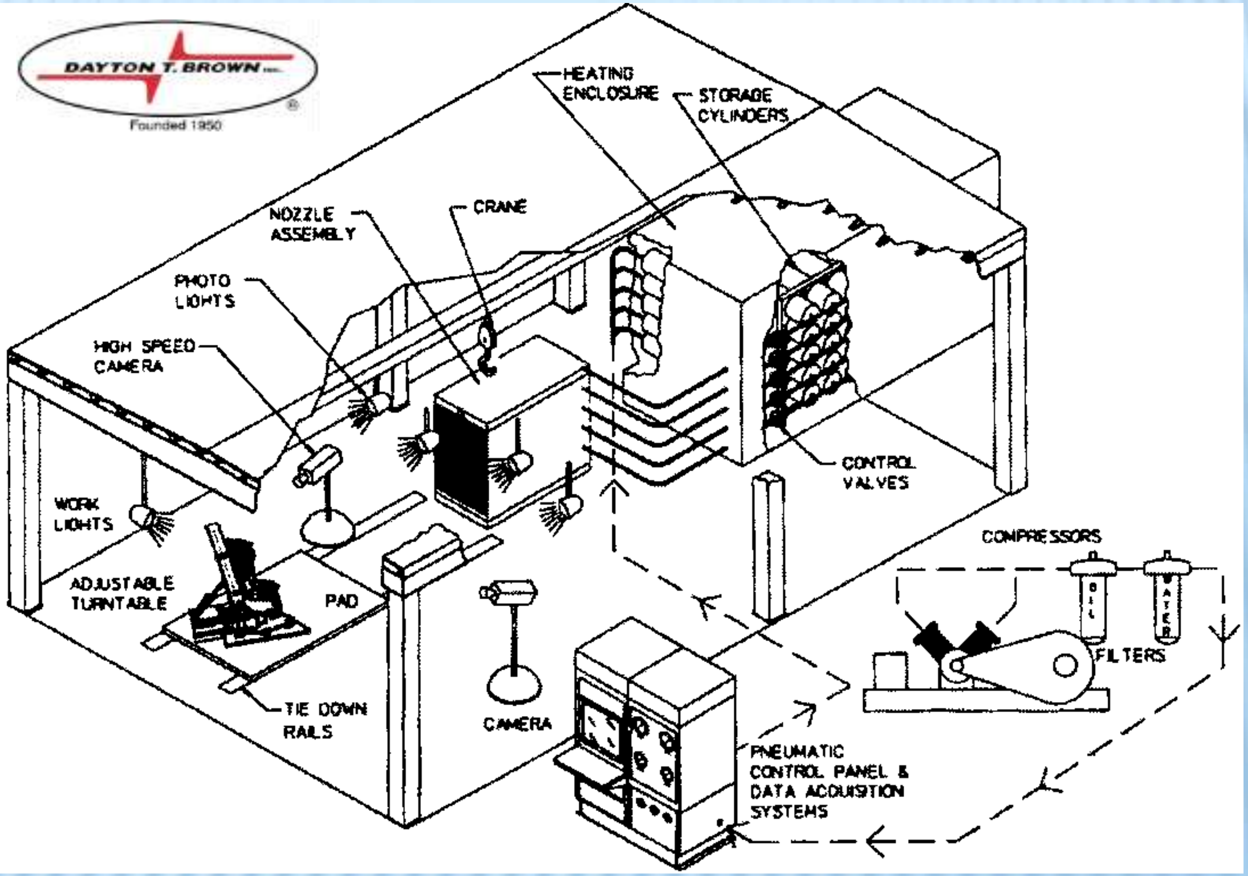

Figure 1

TEST FACILITY

A brief overview of the facility operation follows. A detailed description of each major facility subsystem and resultant velocity profile will be presented as part of this paper.

The enhanced Windblast Facility is illustrated in Figures 1 and 2 and is composed of four major subassemblies. These consist of the air supply and storage module, the main air flow control valve module, the plenum and nozzle module, and the automated control and data acquisition system.

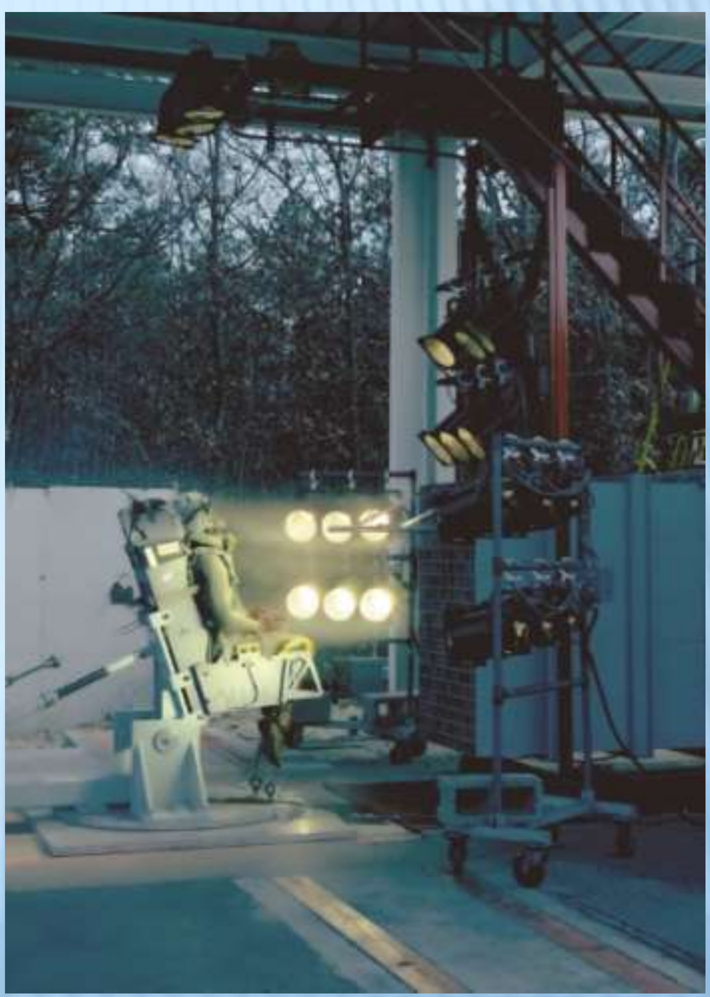

Figure 2

TEST FACILITY DESCRIPTION

The high pressure compressors deliver air through the control panel to the gas cylinder storage bank. These cylinders are stored and maintained in a heated enclosure. On command, the stored air is allowed to expand through the main airflow control valves and into the plenum chamber.

In the plenum chamber the individual banks of expanding air are mixed and directed down the flow straightening nozzle assembly through the orifice plate. Upon exiting the nozzle, the air impinges on the item under test which is mounted on the positioning turntable. The effects of the dynamic pressure profile on the test item are recorded by the high speed cameras, and force transducers for subsequent analysis of failures.

Permanent volume change of the storage system tubes exceeds 10% due to pressurization to 3000 psi. Randomly selected stainless steel attaching tubes are burst tested to verify that no detrimental metal fatigue has resulted from pressure cycling. The delivery manifold heavy wall tubing is visually inspected and weld areas are magnetic particle inspected if anomalies are suspect.

MAIN AIR FLOW AND CONTROL VALVES

The main airflow control valves can be considered the heart of the Enhanced Windblast Test Facility. These five control valves are subject to extremely demanding operational requirements and environmental conditions. Each of the five 3 inch full bore ball valves flow approximately 150,000 CFM of heated expanding air each time they are cycled open. There is a 2,000 psi pressure drop across the valve and air velocities reach supersonic levels through the valve throat. The valves use pressure-actuated seats with locked in non-metallic face seals.

To assure a tight seal at low upstream pressures a 'C- spring' forces the seat against the ball. At higher upstream pressures the seat is forced against the ball by the differential pressure achieved between the area of the non-metallic seat and the outer O-ring seal. This provides extremely reliable sealing characteristics under normal usage; however also created several unique engineering concerns as installed in the windblast facility. Reference Figure 3.

Figure 3 - Main Air Flow Control Valves

MAIN AIR FLOW AND CONTROL VALVES, (CONTINUED)

In order to achieve the required rise time to peak velocity (125 - 150 milliseconds) the valves are required to cycle from closed to full open in under 75 milliseconds. This puts extreme loads on the unsupported regions of the non-metallic valve seats. Several iterations of seat material and geometry were required until the valve design was optimized for this specific application. The pressure actuated seat also presented design challenges in developing a mechanical linkage to ensure simultaneous operation of all five valves, provide adequate strength to resist initial valve opening torque requirements and yet maintain the lightest weight possible to reduce the inertial forces associated with the rapid accelerations required to achieve the demanding 75 millisecond opening time. This was achieved by using heat treated alloy steel center hubs at the valve stem interface and attaching light weight high strength aluminum torque arms and linkage straps to transfer actuator loads to achieve the required valve stem torque. All pivot attachment locations were fitted with press fit aluminum-bronze bushings and close tolerance shoulder bolts to minimize required input loads and ensure smooth reliable operation (reference Figure 4).

The valves are actuated by a pair of pneumatic actuators which apply a pure torsion to the linked main air flow control valve stems through two extended torque arms. These actuators were carefully sized to achieve the balance of required load capability and speed of stroke to satisfy the operational requirements of the facility. The valve actuators are supplied moisture free gaseous nitrogen through a four-way directional control valve. The operation of this valve is automatically controlled and sequenced by the PLC in the control panel. The valve linkages are designed to allow for independent and isolated operation of each valve bank. This allows for conservation of air in cylinder banks not required for test item exposure.

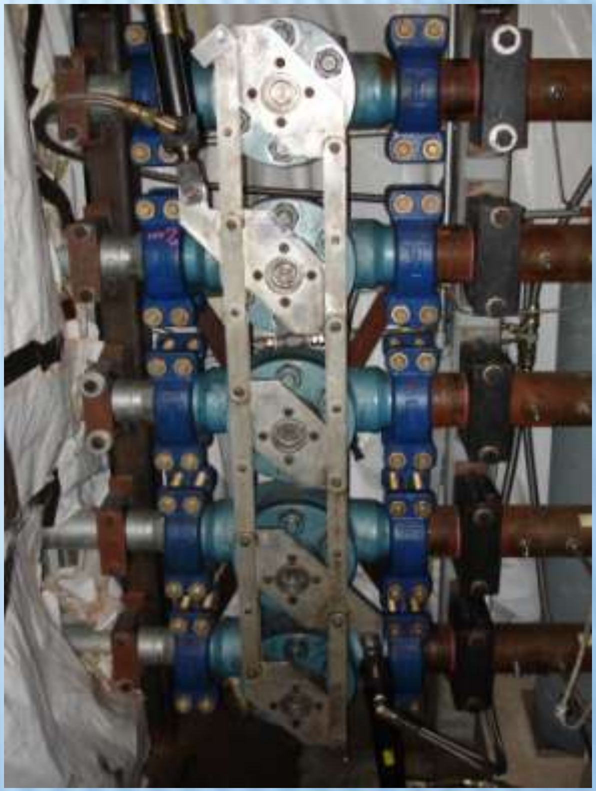

Figure 4 - Main Air Flow Control Valves

PLENUM AND NOZZLE

The five main air flow control valves link the five banks of storage bottles and the air delivery piping to the plenum chamber and nozzle module (reference Figure 5). The control valves establish the gross performance characteristics of the facility such as the air velocity onset and decay profiles and the maximum achievable velocity, while the plenum and nozzle control the finer performance characteristics such as the uniformity of flow and velocity across the nozzle face.

The plenum chamber is symmetrically fed stored air by ten 3-inch schedule 40 delivery pipes. These pipes attached to each side of the plenum chamber and are interconnected by an aluminum tube perforated by fifty 1.00 inch diameter holes. The holes are directed toward the back plate of the plenum and allow for the uniform expansion of air into each of the five individual sections of the plenum chamber.

PLENUM AND NOZZLE, (CONTINUED)

The air pressure developed in the plenum chamber is higher than atmospheric thus causing the air to rush through the orifice plate and the five foot long flow straightening tubes of the nozzle. The orifice plate has a hole corresponding to each of the 240 three inch square aluminum tubes of the nozzle. The holes in the orifice plate, each varying in diameter, serve to regulate the total airflow through each flow straightening tube. Reference Figure 5.

Figure 5

The diameters of these holes were determined empirically by measuring the pressure in the center of each tube and adjusting the hole diameters (i.e.: orifice area) until a uniform pressure distribution was achieved. Confident that a uniform pressure profile was achieved in the tubes the velocities were surveyed by Dayton T. Brown, Inc. 60 inches from the nozzle face at the typical location of test item exposure. At a later date these same velocity surveys were completed by the Human Systems Division, Biodynamics & Acceleration Branch, located at Wright- Patterson Air Force Base, OH. A sampling of this data will be presented as part of this paper.

AUTOMATED CONTROLS AND DATA ACQUISITION SYSTEMS

As part of the facility enhancement project the control and data acquisition systems were targeted to receive major improvements. The control of the Enhanced Windblast Facility is completely automated. A programmable logic controller (PLC) controls the sequencing of all required events to complete a windblast test. This sequence includes the blowing of a warning siren, the turn on of high intensity photographic lights, the initiation of high speed cameras and video systems, the initiation of the data acquisition system, and the actuation of the main airflow control valves. The desired duration of the windblast event is variable between 0.1 to 5.0 seconds and can be selected prior to initiation of test.

Due to the violent nature of the windblast event many system safeties have been incorporated into the operating system to ensure the safety of test personnel and test items. If all required systems are not operational or if DTB test personnel deem it necessary to abort the test, the windblast test technician need only to release a spring loaded 'dead man' switch to suspend the automated test sequence.

The control console also includes an automated adjustable charging valve to allow for unattended air storage bottle replenishment to a desired test condition fire pressure. This convenience reduces support staff levels during testing, and allows the system to charge unattended to a *‘ready for test'* configuration.

The data acquisition system is dedicated and stands alone. The system is PC based and consists of a National Instruments, PCI 6071E, 32 channel differential input data acquisition card. Signal conditioning is accomplished using Validyne amplifiers. Data is sampled at 1000 hertz and is filtered using a twenty-five point median curve fit. Data can be acquired from various types of transducers including strain gage, differential pressure, accelerometers, displacement transducers, thermocouples and load cells. Critical data can be viewed on screen immediately after test to verify test condition parameters were met.

VELOCITY PROFILE UNIFORMITY AND PERFORMANCE VERIFICATION

As stated earlier a series of windblast firings were performed in conjunction with the Wright-Patterson Air Force Base Human Effectiveness Directorate, Biodynamics & Acceleration Branch. Their objective was to answer several questions related to the performance of the new facility. Namely would the DTB Enhanced Windblast Test Facility provide airflow uniformity at the required test airspeeds, would the test articles, manikin, and ejection seat be fully covered by the uniform airflow, and would the facility produce air velocity onset and decay profiles as established by the original facility?

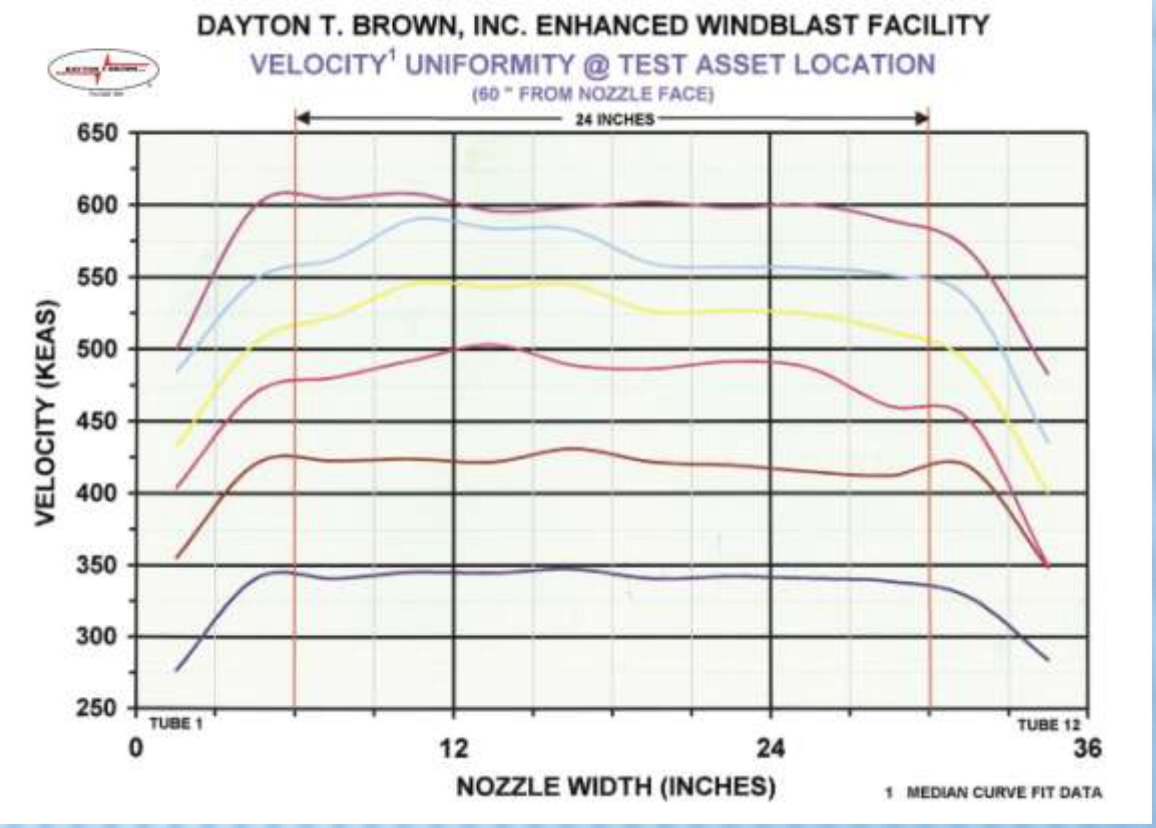

Figure 6

VELOCITY PROFILE UNIFORMITY AND PERFORMANCE VERIFICATION, (CONT'D)

To answer these questions the Air Force and DTB performed a series of 39 test firings at nozzle velocities of 375, 475, 625 and 725 KEAS and recorded velocity profile data using an array of 63 pressure transducers. The pressures were then converted to airspeed in accordance with MIL-STD-1524. The data presented in Figure 4 was acquired by the Air Force from eight 375 KEAS nozzle velocity firings with 1 pressure measured at the nozzle pitot rake and 63 pressures measured at 58.7 inches from the nozzle face for each firing. The plot illustrates the uniformity of the airflow in a region of the nozzle 55 inches tall and 30 inches wide centered about the nozzle centerline in both axis. The airflow outside this region should be considered the transition zone to the stagnated surrounding air.

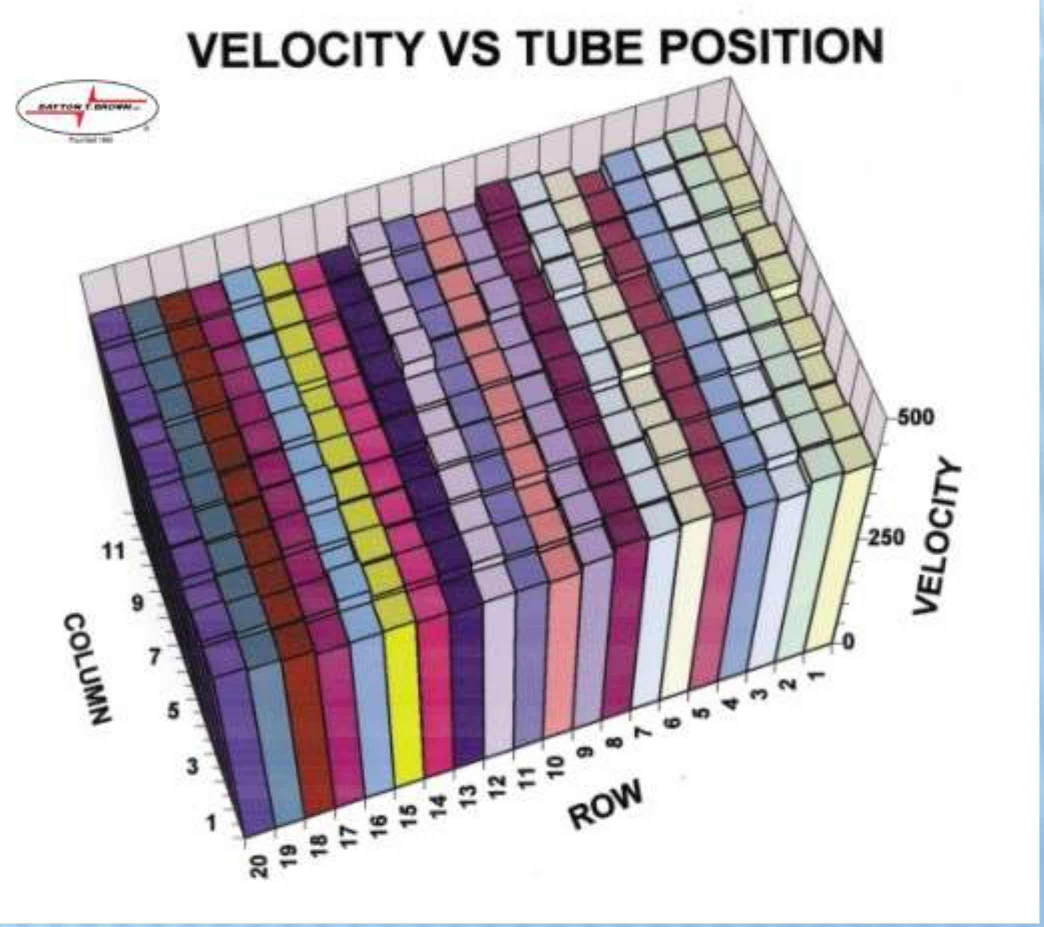

Figure 7

VELOCITY PROFILE UNIFORMITY AND PERFORMANCE VERIFICATION , (CONT'D)

UNIFORMITY OF VELOCITY PROFILE

TUBE VELOCITY (KEAS) @ 1600 PSI FIRE PRESSURE

BANK	ROW	Y \ X	WEST 1 (1.5)	2 (4.5)	3 (7.5)	4 (10.5)	5 (13.5)	6 (16.5)	7 (19.5)	8 (22.5)	9 (25.5)	10 (28.5)	11 (31.5)	EAST 12 (34.5)	RAKE	ROW AVG KEAS	ROW STD DEV	ROW MAX KEAS	ROW MIN KEAS
1	1	1.5	412	413	402	407	422	408	435	437	416	428	428	419	376	419	11.2	437	402
1	2	4.5	417	424	422	426	425	433	417	424	425	434	431	435	386	426	5.9	435	417
1	3	7.5	399	422	410	414	427	432	440	425	424	429	424	430	*	423	10.9	440	399
1	4	10.5	406	417	413	423	432	432	435	433	429	424	425	428	*	425	8.9	435	406
2	5	13.5	399	411	414	423	420	433	419	417	430	418	421	405	388	417	9.5	433	399
2	6	16.5	416	416	428	412	407	429	416	418	406	420	427	426	372	418	7.8	429	406
2	7	19.5	407	414	410	413	402	420	419	416	436	440	434	437	372	421	12.8	440	402
2	8	22.5	413	410	413	410	420	432	425	428	418	410	427	442	380	421	10.2	442	410
3	9	25.5	397	412	404	416	414	413	417	415	436	419	421	413	377	415	9.3	436	397
3	10	28.5	383	394	390	409	400	413	422	416	421	420	426	423	375	410	14.6	426	383
3	11	31.5	387	397	397	407	417	420	417	413	419	417	419	429	377	412	12.2	429	387
3	12	34.5	386	405	401	412	420	409	419	449	434	432	423	441	381	419	17.8	449	386
4	13	37.5	383	405	392	409	400	413	420	423	420	412	404	409	378	408	11.8	423	383
4	14	40.5	390	404	394	399	404	407	400	395	393	396	406	407	376	400	6.1	407	390
4	15	43.5	394	403	408	405	409	413	409	395	409	408	409	414	379	406	6.2	414	394
4	16	46.5	394	418	388	401	428	417	432	419	413	405	410	425	378	412	13.5	432	388
5	17	49.5	392	405	404	418	418	421	426	422	415	406	409	416	374	413	9.4	426	392
5	18	52.5	401	405	403	404	405	409	416	409	420	421	410	418	376	410	7.0	421	401
5	19	55.5	406	418	410	410	417	425	418	408	419	420	411	422	374	415	6.0	425	406
5	20	58.5	413	424	404	425	429	425	445	431	437	422	411	424	378	424	11.3	445	404
											AVG NOZZLE KEAS			416	378	416	10.1	449	383

* NO NOZZLE PITOT RAKE INSTALLED

WEST TO EAST VELOCITY DISTRIBUTION

BANK 1	BANK 2	BANK 3	BANK 4	BANK 5
418 428	416 423	404 423	403 410	412 419

12.2 STANDARD DEVIATION FOR ENTIRE NOZZLE

Figure 8

All velocities were normalized to 375 KEAS at the nozzle pitot rake location. A statistical analysis was performed on the plotted data grid which consisted of 345 velocity measurements. This yielded an average velocity of 347 KEAS, a standard deviation (SO) of 22 KEAS, and an east/west nozzle distribution of 343/351 KEAS. Data frequency analysis yielded a typical bell curve distribution with 65% of the measured velocities falling between 330 to 360 KEAS.

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