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Metrology Measurements of the DSTO Transonic Wind Tunnel Store Support Arm

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ABSTRACT

The Defence Science and Technology Organisation operates a transonic wind tunnel that has a six degree of freedom store support system. This support system enables models under test to be translated and rotated in the test section to predefined positions and orientations. The accuracy of the translational and rotational readings from the store support system must be checked periodically to ensure that they are within acceptable uncertainty limits, and therefore provide quality assurance for test clients. This document details metrology measurements that were conducted during February and March 2013 on the store support together with subsequent results and adjustments applied to the associated calibration curves.

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Executive Summary

The Defence Science and Technology Organisation maintains and operates a number of experimental aerodynamic test facilities including a transonic wind tunnel. This facility has three model support systems including a sidewall turntable, a main model support, and a store model support. The store support system provides six degrees of freedom, enabling models under test to be translated and rotated in the test section to predefined positions and orientations. The store support arm uses encoders, linear displacement transducers, and resolvers to measure the raw motion of its actuation components. These readings are converted by the data acquisition system into engineering units through the use of a number of calibration curves. The accuracy of the translational and rotational readings from the store support system must be checked periodically to ensure that they are within acceptable uncertainty limits, and therefore provide quality assurance for test clients.

A series of metrology measurements were conducted on the store model support for this purpose during February and March 2013. The movements of the store support arm were primarily measured by a portable coordinate measuring machine, a precision spirit level, and a mechanical clinometer. These instruments were used to take translational and rotational readings against a reference metrology arbor installed on the store support. Readings were compared with those obtained from the store support system data acquisition system. This considered both absolute readings and relative readings.

Results were used to update the data acquisition system calibration curves which convert the raw readings into output engineering units. No significant changes had occurred, and only minor offset adjustments were applied to the vertical, axial, upstream yaw, and pitch calibration curves.

The final uncertainties of the store support system exceed those defined in the original specifications, and this was attributed in part to the uncertainty in the metrology methodology. The original specifications were based on measurements under laboratory controlled conditions and the use of highly accurate laser interferometry. They were not determined with the store support assembled in the test section.

It is recommended that the metrology measurements are repeated within five year intervals. Improved methods to measure the translational and rotational movements should also be investigated.

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Abbreviations and Acronyms

ADF	Australian Defence Force
ASE	Aero Systems Engineering
CMM	Coordinate Measuring Machine
DAS	Data Acquisition System (ASE2000LX), designated as WP1900
DSTO	Defence Science and Technology Organisation
DS/US	Downstream / Upstream
LDT	Linear Displacement Transducer
LPRS	Length of Pitch Rotation Station
MS	DSTO TWT Main Model Support, designated as WP1730
PES	Plenum Evacuation System, designated as WP1300
SS	DSTO TWT Store Model Support, designated as WP1740
TS	DSTO TWT Sidewall Turntable Model Support, designated as WP1750
TWT	Transonic Wind Tunnel
σ	Standard deviation

Data Acquisition System (ASE2000LX) Parameters

Motion	Raw Parameter Name	Calibration Curve Name	Output Parameter Name
Vertical LDT Position	ZE110_RAW	ZE110	EU_XFB
Axial LDT Position	ZE210_RAW	ZE210	EU_ZFB
DS Yaw Encoder Angle	ZE220_RAW	ZE220	n/a
US Yaw Encoder Angle	ZE230_RAW	ZE230	n/a
Lateral Position (DS+US)	n/a	n/a	EU_YFB
Total Yaw Angle (DS+US)	n/a	n/a	EU_PSIFB
Pitch Encoder Angle	ZE240_RAW	ZE240	EU_THETAFB
Roll Encoder Angle	ZE250_RAW	ZE250	EU_PHIFB

Tunnel Gravity Axis System Sign Convention

The TWT tunnel gravity axis system is an Earth fixed axis system, which has its z-direction aligned with the gravity vector. The origin is located at the nominal centre of the test section, which corresponds to the axial and vertical centre of the sidewall turntable, and is 400 mm laterally from the inner sidewall. The axial location is defined as station 5257. The axes are X_g, Y_g, and Z_g and are defined as follows:

X_g Gravity longitudinal axis, perpendicular to the gravity vector and contained in a plane parallel to the support system pitch plane, positive upstream.

Y_g Gravity lateral axis, perpendicular to the gravity X-Z plane, positive direction determined by the positive X_g and Z_g directions in conjunction with the right-hand rule.

Z_g Gravity vertical axis, collinear with the gravity vector, positive toward the tunnel floor.

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1. Introduction

The Defence Science and Technology Organisation (DSTO) maintains and operates several experimental aerodynamic test facilities including a transonic wind tunnel (TWT). This is the only facility of its kind in Australia, and has been operational since 2000 enabling aerodynamic research to be carried out for the Australian Defence Force (ADF). The TWT operates in the transonic speed range where both viscosity and compressibility effects are important and are difficult to model using other means. This facility is a critical element of Australia's indigenous strategic store clearance capability.

The TWT is a closed return-circuit continuous flow tunnel. A schematic drawing of the aerodynamic circuit and main components of the facility is shown in Figure 1. The facility can achieve Mach numbers ranging from 0.3 to 1.2 continuously variable, and Mach 1.4 with a fixed nozzle. A total pressure range from 30 kPa to 200 kPa is attainable. Flow is generated by a two-stage axial flow compressor powered by a 5.3 MW variable speed electric motor. The test section is 0.806 meters wide by 0.806 meters high and 2.7 meters long with a slotted top and bottom walls and interchangeable solid or slotted sidewalls.

An auxiliary plenum evacuation system (PES) provides the capability for pressurisation, evacuation and an additional means for Mach number control. A water-cooled heat exchanger in the settling chamber is used to control the air temperature in the test section. Turbulence conditioning screens and a 16:1 contraction provide good quality flow.

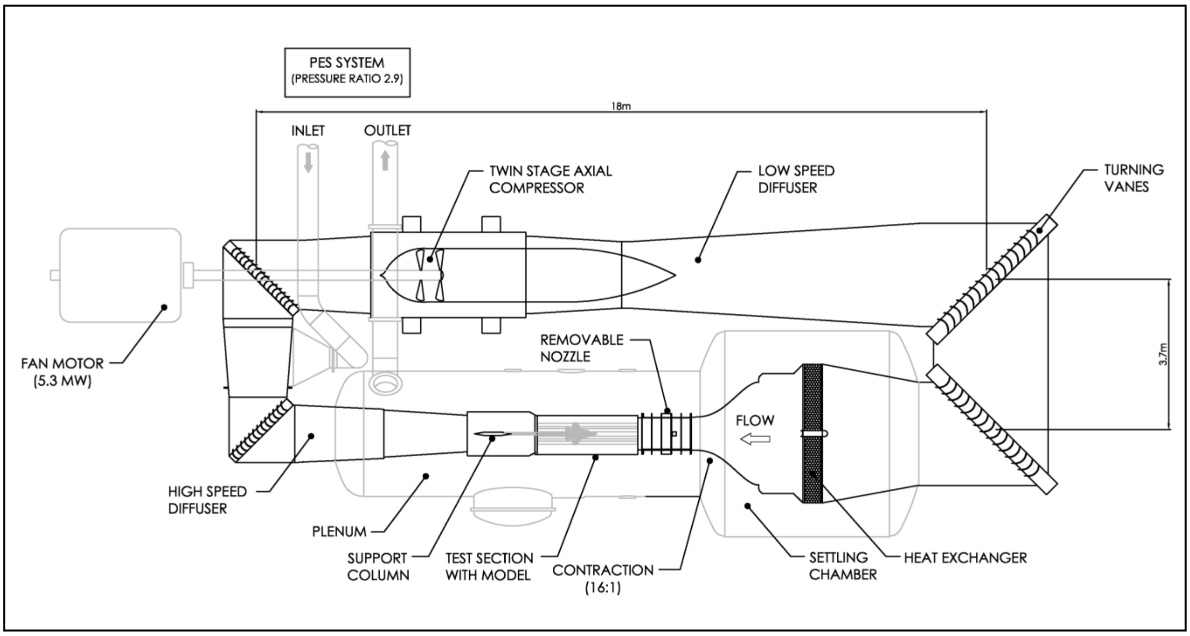


Figure 1: The DSTO transonic wind tunnel aerodynamic circuit

The TWT facility has three independent model support systems:

- Main model support (MS) for freestream tests of full models (pitch and roll capability)
- Store model support (SS) to position a store model below a parent model for store release tests (full six degree of freedom movement)
- Sidewall turntable model support (TS) for half model tests (pitch rotation).

The accuracy of the readings from these model support systems must be checked periodically to ensure that they are within acceptable uncertainty limits, and therefore provide quality assurance for test data. A series of metrology measurements were conducted on the store model support for this purpose during February and March 2013.

This document details the methodology and results of these metrology measurements. A description of the store model support system is provided in Section 2, and the metrology equipment used is detailed in Section 3. Methodology and results are presented in Section 4 with a summary of results provided in Section 5.

Details of previous metrology checks on the store model support are included in references [1], [2], and [3].

2. TWT Store Support System Description

The TWT store model support (SS) is a six degree of freedom model support enabling models under test to be translated and rotated in the test section to predefined positions and orientations. It is capable of providing axial, lateral, vertical, roll, pitch and yaw motions. The SS is a removable fixture which mounts on the port side of the main model support (MS) movable strut. Vertical motion is provided by the MS vertical drive with a linear displacement transducer (LDT) providing position feedback. Axial motion is provided by the axial drive, also with a LDT providing position feedback. Lateral motion is provided by actuating both yaw drives through equal but opposite angles. Yaw motion is provided by the upstream yaw drive. Both of the yaw drives incorporate encoders, mounted directly to the yaw pivots with no intermediate gearing, which provide angular position readout. Pitch and roll motions are provided by the pitch and roll drives respectively. The pitch angle reading is provided by an encoder mounted directly at the pitch pivot with no intermediate gearing. The roll angle reading is provided by a resolver is coupled directly to the output shaft.

The store support arm is shown installed in the test section in Figure 2 together with the definition of tunnel axis system. The axial centre is defined at the TWT station coordinate STA 5257, and corresponds to the geometric centre of the sidewall turntable. The lateral centre is defined 400 mm from the inner sidewall, however it should be noted that the total test section width is 806 mm. The vertical centre corresponds to the midpoint between the top and bottom wall, as the walls are divergent the distance from top/bottom wall varies along the test section length. The tunnel axis system is further described in the Notation.

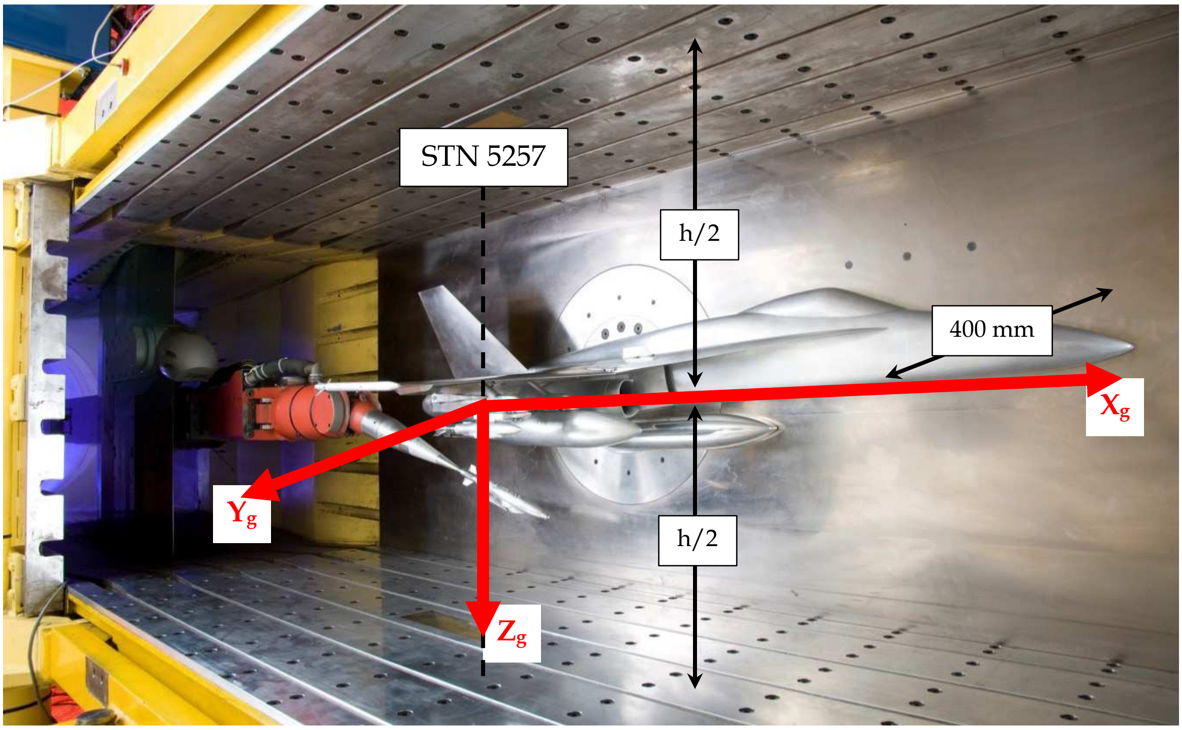


Figure 2: Store model support in the TWT test section

A full description of the store model support can found in §3.2 of reference [4]. Specifications for the SS are provided in Table 1.

Table 1: TWT store model support range of motion and design specification

	Range of Motion	Motion Rates	Setting Accuracy	Position Reading Accuracy
Axial Translation[1]	500 mm	0 to 20 mm/s	± 0.3 mm	± 0.1 mm
Lateral Translation[2]	500 mm	0 to 20 mm/s	± 0.6 mm	± 0.1 mm
Vertical Translation[3]	500 mm	0 to 20 mm/s	± 0.2 mm	± 0.1 mm
Roll Angle	± 190 deg	0 to 10 deg/s	± 0.50 deg	± 0.10 deg
Pitch Angle	± 30 deg	0 to 5 deg/s	± 0.10 deg	± 0.01 deg
Yaw Angle	± 30 deg	0 to 5 deg/s	± 0.10 deg	± 0.01 deg

NOTES:
1. Axial motion ranges from 250 mm upstream to 250 mm downstream of station 5257.
2. Lateral motion ranges from 310 mm portside to 190 mm starboard side of the test section centreline.
3. Vertical motion ranges from 320 mm below to 180 mm above the test section centreline.

The raw readings from the drive LDT's, encoders, and resolvers are converted into engineering units by the TWT main control and data acquisition program, ASE2000LX, and includes application of calibration curves. The relevant ASE2000LX parameter names for each degree of motion are provided in the Notation.

Predefined 'testplans' are used in conjunction with an ASE2000LX 'configuration' in order to conduct testing. The testplans are created using an Excel workbook environment and define the matrix of test conditions and list of model traverse positions to step through together with various other constants.

As the store model support set-points are defined relative to a user-determined store reference position, ASE2000LX needs to convert these to absolute coordinates. The full description of the conversion process and algorithms is provided in §6.7.2 of reference [5].

3. Metrology Equipment

The equipment used for the metrology measurements of the store model support are listed below and shown in Figure 3:

- Metrology arbor
- Reference V-blocks (Eclipse No 230)
- Portable coordinate measuring machine (CMM - Faro Gage Model F04)
    - translational measurement uncertainty of ± 0.01 mm
- Frame spirit level (Level developments 100 mm, 0.1 mm/m)
    - 20 sec sensitivity per 2 mm division (± 0.006 deg)
- Mechanical clinometer (Level developments No. 83, 120 mm, 0.3 mm/m)
    - 60 sec sensitivity per 2 mm division (± 0.017 deg)
- Laser level (Leica LINO L2P5)
- Height gauge (Starrett No 752A-18)
    - used only as a means to support the laser level

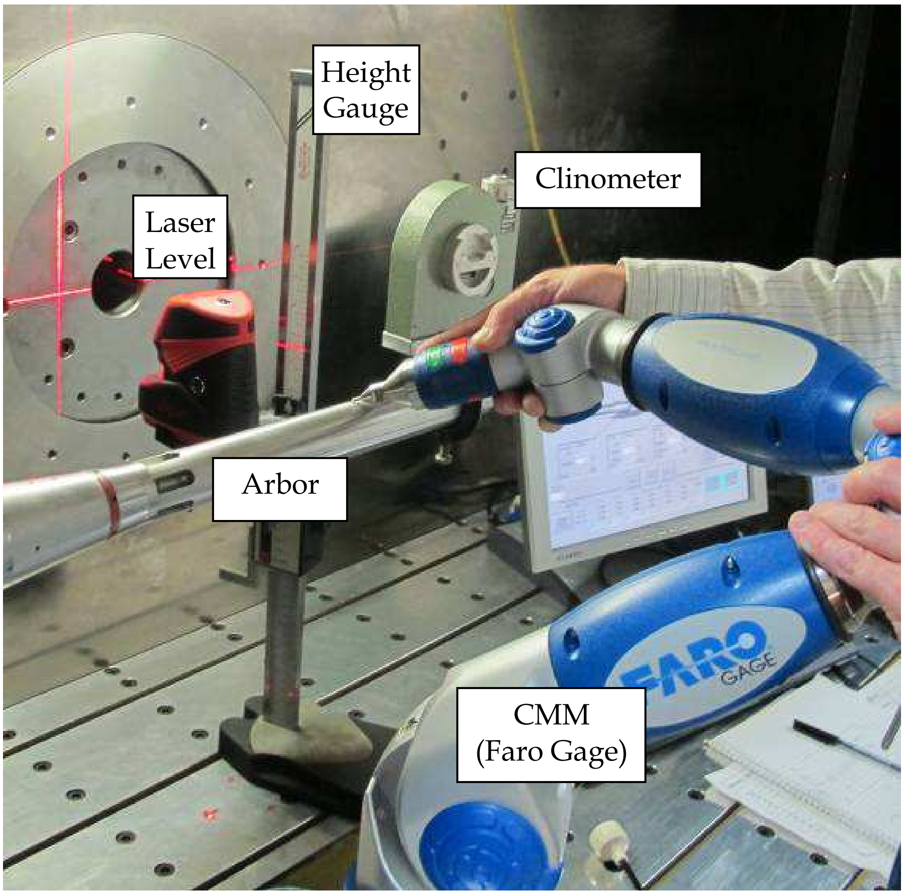


Figure 3: Metrology arbor, clinometer, CMM, height gauge, and laser level

4. Measurement Methodology and Results

The following sections present the methodology used to measure absolute and relative positions for each degree of motion of the store support system. The main results of these metrology measurements are also provided. Full results are documented in reference [6].

4.1 Axial (X_g) Measurements

The nominal axial centre of the test section (EU_XFB = 0) corresponds to the TWT station coordinate STA 5257 which coincides with the geometric centre of the turntable. The arbor end face was set to EU_XFB = 0, (i.e., the test section axial centre position). In order to achieve this, the 'Length of Pitch Rotation Station' (LPRS) had to be defined in the testplan. This is the distance between the pitch pivot pin on the store support arm and the end face of the arbor, and was determined to be 621.62 mm (i.e., the pitch arm length plus the arbor length).

To determine the absolute axial position offset a reference plane for the CMM was defined at the forward face of the model support system section, see reference [7], which corresponds to STA 6205 (see Figure 4). The nominal axial distance from the turntable centre (STA 5257) to the forward face of the model support system section (STA 6205) is thus 948 mm. CMM metrology measurements indicated a dimension of 947.97 mm.

Figure 4: CMM measuring the STA 6205 reference face

With the store support position set to 0 (EU_XFB = 0), CMM measurements were taken between the reference stations and the front of the arbor as shown in Figure 5. Repeat measurements revealed a variation in these measurements of up to ±0.04 mm.

For relative motion, the store support position was set to 0 (EU_XFB = 0), and the CMM was zeroed against the arbor face. Relative measurements were then taken in the X direction, incrementing EU_XFB in 50 mm steps, with measurements recorded by ASE2000LX data acquisition program. Metrology results are provided in Table 2.

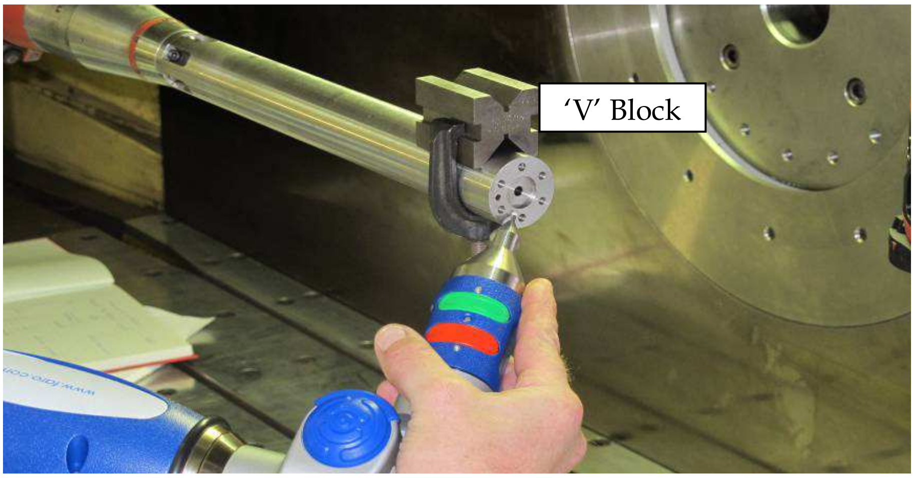


Figure 5: CMM measuring the front face of the arbor

Table 2: Axial position metrology results

Offset

STN 6205 to front of arbor	0.17	mm	(arbor forward)
STN 5257 to front of arbor	0.14	mm	(arbor forward)
STN 5257 to front of arbor (repeat)	0.15	mm	(arbor forward)

Relative Motion

ASE2000LX Run: 2542

TC_POINT	ZE210_RAW	ZE210 [mm]	EU_XFB [mm]	CMM Metrology Reading [mm]	Zero Corrected Error [mm]
0	304.44	-280.83	-0.01	0.00	0.00
1	354.40	-230.83	49.99	49.93	0.07
2	404.35	-180.82	99.99	99.93	0.08
3	454.33	-130.82	149.99	149.90	0.11
4	504.36	-80.82	199.99	199.91	0.10
5	554.40	-30.83	249.99	249.92	0.08
6	554.40	-30.83	249.99	249.92	0.08
7	234.51	-350.80	-69.98	-69.90	-0.07
				σ	0.06

Estimated zero offset uncertainty (2σ):	± 0.04	mm
Estimated relative motion uncertainty (2σ):	± 0.12	mm

The uncertainty of the zero offset measurement was based on the variation in the three readings, and the uncertainty of the CMM. The uncertainty of the relative motion measurements was based on the uncertainty of the CMM readings and the standard deviation (2σ) of the zero corrected error results.

4.2 Test Section Floor Measurements

Prior to checking the vertical position and motion, the flatness of the slatted top/bottom walls needed to be quantified as it impacts the uncertainty that the zero vertical reference can be set to. The slats on the bottom wall were measured relative to the furthest slat on the port side. The CMM was zeroed at this slat and relative vertical measurements of the other slats were measured across the tunnel floor. Results are provided in Table 3.

Table 3: Tunnel floor measurements

Slat Number	CMM Reading [mm]
Reference 0	0.00
1	0.00
2	-0.20
centre port 3	-0.25
centre starboard 3	-0.06
4	-0.18
5	-0.11
6	-0.12
σ	0.09

4.3 Vertical (Z_g) Measurements

The nominal vertical centre of the test section (EU_ZFB = 0) corresponds to the geometric centre of the test section, half-way between the top and bottom walls. The actual distance from the top/bottom wall depends on the axial location due to the 20 minute divergent nature of these walls. Due to this wall divergence, it was important to take the vertical measurements at a defined axial position. The laser level was used to project a vertical plane around the test section walls and define a fixed axial position on the arbor, on the test section bottom wall, and on the test section top wall. The CMM was then used to measure the test section height at this plane, and subsequently the arbor vertical position relative to the tunnel centreline was calculated. Measurements were taken at two axial locations, approximately 105 mm and 260 mm upstream of the junction of the SS and arbor interface.

The store support arm was then moved in 80 mm relative steps in the vertical direction with measurements recorded by ASE2000LX data acquisition program.

Results of the offset and relative vertical measurements are provided in Table 4. The LPRS value was set to 621.26 mm, the same as that used for the axial measurements.

Figure 6: CMM measuring the arbor vertical position in the test section

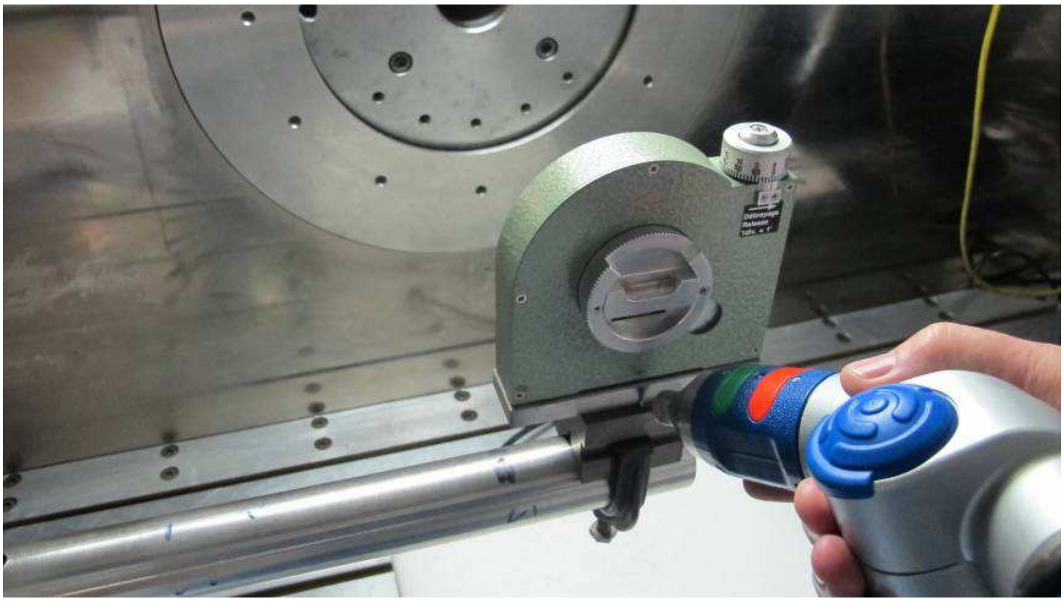


Figure 7: CMM measuring vertical position relative to centreline reference

Table 4: Vertical position metrology results

Offset

Z1 metrology measurement	0.86	mm	(arbor below centreline)
Z2 metrology measurement	0.75	mm	(arbor below centreline)

Relative Motion

ASE2000LX Run: 2543

TC_POINT	ZE110_RAW	ZE110 [mm]	EU_ZFB [mm]	CMM Metrology Reading [mm]	Zero Corrected Error [mm]
0	854.16	1.32	0.04	0.00	0.00
1	774.07	81.32	80.04	80.02	-0.02
2	694.03	161.32	160.04	159.99	0.01
3	614.00	241.32	240.04	239.99	0.01
4	533.97	321.32	320.04	320.01	-0.01
5	934.15	-78.69	-79.96	-80.01	0.00
6	1014.12	-158.69	-159.97	-160.00	-0.01
7	1034.12	-178.68	-179.97	-180.01	0.00
8	854.16	1.32	0.04	0.00	0.00
				σ	0.01

Estimated zero offset uncertainty (2σ):	± 0.20	mm
Estimated relative motion uncertainty (2σ):	± 0.03	mm

The uncertainty of the vertical zero offset measurement was based on an estimate of how accurately the tunnel height could be measured, and how accurately the position of the arbor centre could be measured relative to half of this test section height. This included consideration of how 'flat' the walls were (see Section 4.2). The uncertainty of the relative vertical position measurements was based on the uncertainty of the CMM readings and the standard deviation (2σ) of the zero corrected error results.

4.4 Coning Measurements

Prior to checking pitch and yaw, coning of the arbor needed to be quantified as it affects the uncertainty that the zero reference pitch or yaw can be set to.

The arbor was levelled in pitch using the 120 mm clinometer for a roll of 0 degrees. The store model support roll angle was then rotated to 180 degrees and ±90 degrees, with the 100 mm frame level used to assess the resultant coning angle of the arbor, where 1 division on the frame level is equivalent to 0.006 degrees. (see Figure 8). Results of the arbor coning angles measured are presented in Table 5.

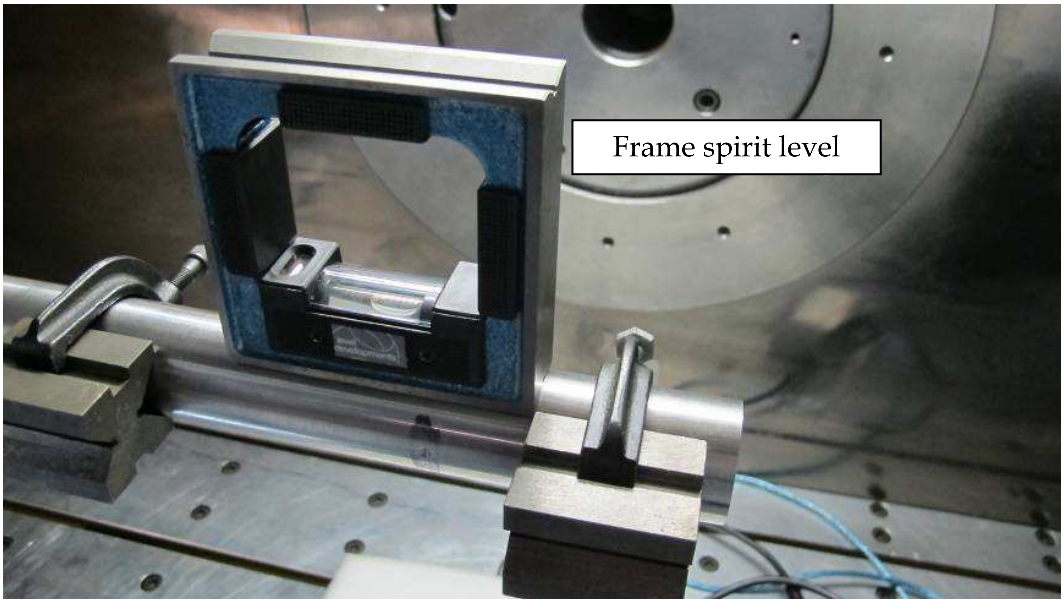


Figure 8: 100 mm frame spirit level aligning the arbor to check for coning

Table 5: Arbor coning angle metrology results

EU_PHIFB [deg]	Coning Angle [deg]	Frame Level Divisions [1 div = 0.006 deg]
0	0.000	0
-90	-0.030	5
90	0.012	2
180	0.006	1

4.5 Pitch Measurements

The arbor was levelled in pitch using the 120 mm clinometer as in the coning check. The arbor yaw was set to 0 degrees as defined by the EU_PSIFB parameter in ASE2000LX. Clinometer readings were then taken for store support pitch increments of 5 degrees over a range of ±30 degrees, with measurements recorded by ASE2000LX at each increment. Results of these pitch measurements are provided in Table 6. The LPRS dimension for pitch measurements was set to 450 mm. This resulted in the arbor mid-point being positioned approximately at the turntable centre position.

Figure 9: 120 mm clinometer measuring the arbor pitch angle

Table 6: Pitch angle metrology results

Offset and Relative Motion

ASE2000LX Run: 2544

TC_POINT	ZE240_RAW [count]	ZE240 [deg]	EU_THETAFB [deg]	Clinometer Metrology Reading [deg]	Error [deg]	Zero Corrected Error [deg]
0	194094	0.141	0.141	0.00	0.141	0.005
1	201360	5.130	5.130	5.00	0.130	-0.005
2	208643	10.131	10.131	10.00	0.131	-0.005
3	215923	15.129	15.129	15.00	0.129	-0.006
4	223207	20.131	20.131	20.00	0.131	-0.004
5	230486	25.129	25.129	25.00	0.129	-0.006
6	237566	29.990	29.990	29.88	0.110	-0.025
7	186798	-4.854	-4.854	-5.00	0.146	0.011
8	179489	-9.853	-9.853	-10.00	0.147	0.012
9	172180	-14.853	-14.853	-15.02	0.167	0.032
10	164871	-19.853	-19.853	-20.03	0.177	0.042
11	157576	-24.843	-24.843	-25.05	0.207	0.072
12	150253	-29.853	-29.853	-30.08	0.227	0.092
13	194078	0.130	0.130	0.00	0.130	-0.005
				offset	0.135	-
				σ	-	0.033

Estimated zero offset uncertainty (2σ):	± 0.031	deg
Estimated relative motion uncertainty (2σ):	± 0.068	deg

The uncertainty of the pitch zero offset measurement was based on the uncertainty from the arbor coning, and the uncertainty from the clinometer reading. The uncertainty of the relative pitch measurements was based on the uncertainty of the clinometer readings and the standard deviation (2σ) of the zero corrected error results.

It should also be noted that the axial drive (ZE210), and vertical drive (ZE110) also moves during pitch movements to maintain EU_XFB = EU_ZFB = 0.

4.6 Roll Measurements

The zero roll reference for the store support arm was not defined for these checks. As such zero roll was taken as that indicated by the EU_PHIFB parameter in ASE2000LX. The arbor was levelled in pitch as per previous measurements. The store support system was then rolled ±180 degrees in 45 degree steps and data recorded by ASE2000LX. The clinometer was seated on the 'V' blocks as shown in Figure 10, and readings were taken for each roll position. The LPRS dimension was set to 450 mm, the same as that used for the pitch measurements.

Figure 10: 120 mm clinometer measuring the arbor roll angle

Table 7: Roll angle metrology results

Relative Motion

ASE2000LX Run: 2545

TC_POINT	ZE250_RAW	ZE250 [deg]	EU_PHIFB [deg]	Clinometer Metrology Reading [deg]	Zero Corrected Error [deg]
0	339.071	0.006	0.006	0.00	0.000
1	159.077	180.000	180.000	179.99	0.005
2	204.071	135.006	135.006	134.95	0.050
3	249.071	90.006	90.006	89.92	0.080
4	294.071	45.006	45.006	44.97	0.030
5	339.071	0.006	0.006	0.00	0.000
6	24.071	-44.994	-44.994	-44.87	-0.130
7	69.071	-89.994	-89.994	-90.00	0.000
8	114.071	-134.994	-134.994	-135.02	0.020
9	159.071	-179.994	-179.994	-180.12	0.120
				σ	0.065

Estimated zero offset uncertainty (2σ):	-	deg
Estimated relative motion uncertainty (2σ):	± 0.132	deg

The uncertainty of the relative roll measurements was based on the uncertainty of the clinometer readings and the standard deviation (2σ) of the zero corrected error results.

4.7 Yaw Measurements

Ideally it would be best to measure the direct angle of the upstream and downstream arms of the SS but this proved to be too difficult without proper alignment references. Consequently, only the final resultant yaw angle of the arbor was measured.

The 'V' blocks were checked for level on the arbor using the clinometer to ensure their top faces were aligned in a common X-Y plane. Similarly, the sides of the 'V' blocks were checked for alignment in a common X-Z plane using the CMM. A discrepancy of less than 0.01 mm was achieved. The 'V' blocks were used to define a single plane and this was measured against the sidewall plane to determine the yaw angles.

The arbor was set to zero degrees yaw and roll as indicated by ASE2000LX. It was then levelled in pitch as per previous measurements. The store support was then yawed through the range of ±15 degrees in 5 degree steps, with data recorded by ASE2000LX. The test section inner sidewall was taken as the yaw reference plane, and the CMM was used to measure the arbor angle with respect to this plane as shown in Figure 8, Figure 9, and Figure 10. The LPRS dimension was set to 529.8 mm. This corresponded to the position of a dimple which was machined into the arbor for lateral measurements (see Section 4.9).

Figure 11: CMM measuring the front 'V' block side face

Figure 12: CMM measuring the rear 'V' block side face

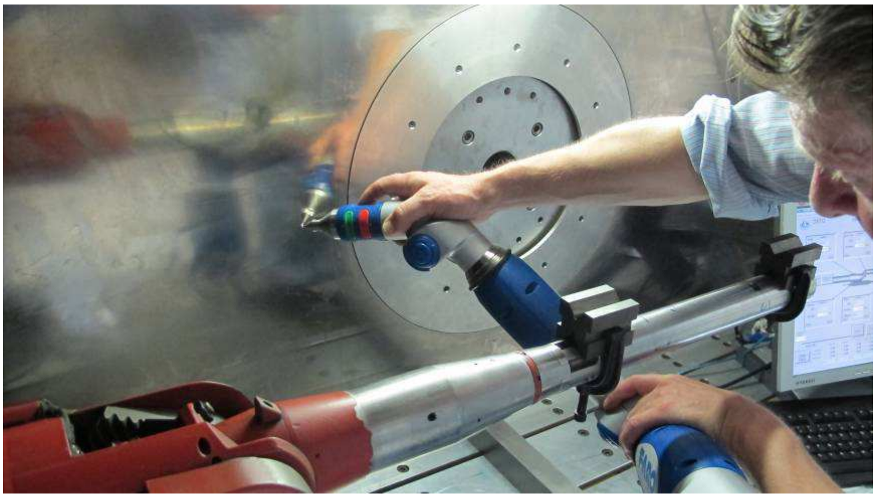


Figure 13: CMM measuring the inner sidewall reference plane

Table 8: Yaw angle metrology results

Offset and Relative Motion
ASE2000LX Run: 2546

TC_ POINT	ZE220_ RAW [count]	ZE230_ RAW [count]	ZE220 [deg]	ZE230 [deg]	EU_PSIFB [deg]	CMM Metrology Reading [deg]	Error [deg]	Zero Corrected Error [deg]
0	117338	211647	19.197	-19.205	-0.008	-0.17	0.162	-0.009
1	106965	229290	26.319	-31.319	-5.000	-5.16	0.160	-0.011
2	95996	247540	33.851	-43.851	-10.000	-10.17	0.170	-0.001
3	127254	194437	12.388	-7.388	5.000	4.80	0.200	0.029
4	136872	177539	5.784	4.216	10.000	9.86	0.140	-0.031
5	146232	160897	-0.643	15.642	14.999	14.78	0.219	0.048
6	117341	211632	19.194	-19.195	0.000	-0.18	0.180	0.009
						offset	0.171	-
						σ	-	0.027

Estimated zero offset uncertainty (2σ):	± 0.055	deg
Estimated relative motion uncertainty (2σ):	± 0.065	deg

The uncertainty of the yaw zero offset measurement was based on the CMM accuracy and metrology repeatability (readings 0 and 6). The uncertainty of the relative yaw position was based on metrology repeatability and the standard deviation (2σ) of the zero corrected error results.

The axial drive (ZE210) also moves during yaw movements to maintain EU_XFB = 0.

4.8 Test Section Width Measurements

Prior to measuring the lateral motion of the store model support the test section width was checked. The width was measured by separating the testing section from the model support section (STA 6205), with both the solid outer and inner sidewalls installed. Access was gained to the CMM from the rear of the test section so that measurements could be made. Three positions were measured; firstly just downstream of the turntable, then centrally further downstream, and finally near the rear end of the test section.

Figure 14: CMM measuring the width of the test section

Table 9: Tunnel width metrology results

Position	CMM Metrology Reading [mm]
1	805.71
2	805.82
3	805.77
average	805.77

The uncertainty of the test section width depends on flatness and parallelism of the test section sidewalls. It was estimated to be ± 0.11 mm based on the repeatability of the CMM readings.

4.9 Lateral (Y_g) Measurements

The nominal lateral centre of the test section (EU_YFB = 0) corresponds to a position 400 mm from the inner sidewall. Note that this is not the lateral geometric centre of the test section given a nominal width of 806 mm. To assist with lateral measurements a dimple was machined into the arbor 258.0 mm from the support end of the arbor. Preliminary metrology measurements against this dimple did not give consistent readings and as such it was subsequently not used.

For checking the lateral motion, the store model support was initially positioned with EU_PSIFB = +0.17 deg, EU_THETAFB = +0.12 deg, and EU_PHIFB = +1.05 deg. This meant that the arbor was aligned parallel to the sidewall, level in pitch and the dimple top dead centre.

The store support zero offset from the nominal lateral centre of the test section was checked to be within ± 0.5 mm. A more accurate measurement could not be achieved due to the uncertainty in this measurement.

To assess relative motion, the SS was moved laterally in 50 mm steps across the test section and the CMM was used to measure the distance from the inner sidewall to the side of the 'V' block. The LPRS dimension was set to 529.8 mm, corresponding to the position of the dimple.

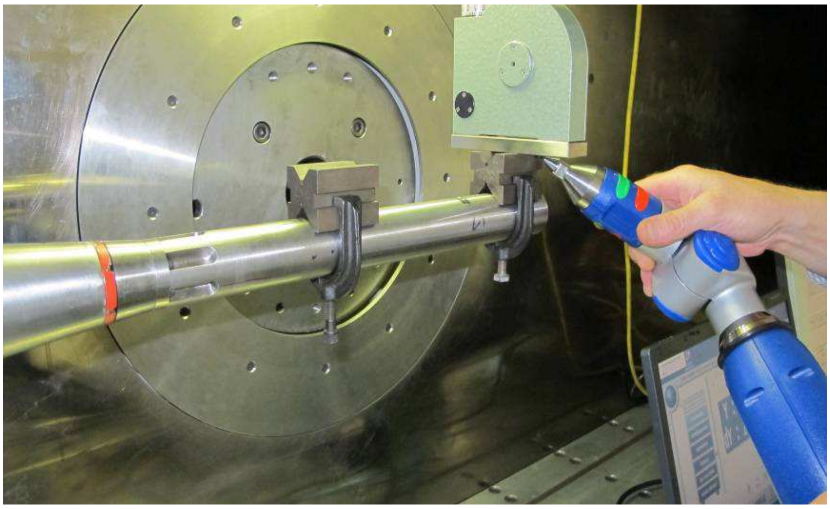


Figure 15: CMM measuring 'V' block side face with respect to the test section inner sidewall

Table 10: Lateral position metrology results

Relative Motion
ASE2000LX Run: 2542

TC_ POINT	ZE220_ RAW [count]	ZE230_ RAW [count]	ZE220 [deg]	ZE230 [deg]	EU_YFB [mm]	CMM Metrology Reading [mm]	CMM Relative Reading [mm]	Zero Corrected Error [mm]
0	117341	211632	19.194	-19.195	-0.11	420.10	0.00	0.090
1	156175	172552	-7.471	7.640	-299.91	119.80	-300.30	-0.412
2	149823	178900	-3.109	3.281	-250.07	170.12	-249.98	0.072
3	143481	185245	1.246	-1.076	-200.12	220.17	-199.93	0.173
4	137133	191592	5.604	-5.434	-150.11	270.25	-149.85	0.239
5	130745	197981	9.991	-9.821	-100.12	320.32	-99.78	0.320
6	124277	204448	14.432	-14.262	-50.10	370.36	-49.74	0.347
7	117685	211040	18.958	-18.788	-0.10	420.42	0.32	0.402
8	110919	217807	23.604	-23.435	49.89	470.41	50.31	0.405
9	103913	224813	28.415	-28.245	99.89	520.46	100.36	0.449
10	96585	232142	33.447	-33.278	149.89	570.51	150.41	0.505
11	117658	211070	18.977	-18.809	0.07	420.18	0.08	-0.010
							σ	0.256

Estimated relative motion uncertainty (2σ): ± 0.513 mm

The uncertainty of the relative lateral position was based on the standard deviation (2σ) of the zero corrected error results, and the estimated variation in repeat measurements.

The axial drive (ZE210) also moves during lateral movements to maintain EU_XFB = 0.

5. Summary of Results

A summary of the position and angular offsets determined from measurements presented in previous sections for each degree of motion is provided in Table 11. This includes the estimated absolute and relative bias uncertainties.

These results were used to update the ASE2000LX calibration curves used to convert the raw readings into output engineering units. The ZE110 vertical LDT curve, ZE210 axial LDT curve, ZE230 upstream yaw encoder curve, and ZE240 pitch encoder curve were corrected for the determined offsets. The ZE220 downstream yaw encoder curve and ZE250 roll resolver curve were not modified. The resultant curves are provided in Appendix A.

Table 11: Summary of store support metrology results

Motion	Offset [deg/mm]	Offset Uncertainty [deg/mm]	Relative Motion Uncertainty [deg/mm]
Vertical LDT Position	0.805	± 0.200	± 0.028
Axial LDT Position	0.150	± 0.040	± 0.122
DS Yaw Encoder Angle	-	-	-
US Yaw Encoder Angle	-	-	-
Lateral Position (DS+US)	-	-	± 0.513
Total Yaw Angle (DS+US)	0.171	± 0.055	± 0.065
Pitch Encoder Angle	0.135	± 0.031	± 0.068
Roll Encoder Angle	-	-	± 0.132

NOTES:

1. The nominal axial centre of the test section (EU_XFB = 0) corresponds to station 5257 which corresponds to the geometric centre of the turntable.
2. The nominal lateral centre of the test section (EU_YFB = 0) corresponds to a position 400 mm from the inner sidewall. The test section width is 806 mm.
3. The nominal vertical centre of the test section (EU_ZFB = 0) corresponds to the geometric centre between the top and bottom walls. The actual distance from the top/bottom wall depends on the axial location due to the divergent nature of these walls.
4. The total yaw angle offset is believed to be caused by the upstream yaw encoder; as such this was applied to correct the ZE230 upstream yaw encoder curve.
5. The effect that the yaw and pitch uncertainty has on the axial, lateral and vertical positions has not been taken into account.

The summary of the store support metrology results are also documented together with the ASE2000LX curves in reference [8].

6. Conclusions

A series of metrology measurements were conducted on the transonic wind tunnel store model support system in March 2013. These were used to assess the accuracy of the translational and rotational readings from the ASE2000LX data acquisition system. No significant changes had occurred, and only minor offset adjustments were applied to the vertical, axial, upstream yaw, and pitch calibration curves.

The final uncertainties of the store support system exceed those defined in the original specifications, and this was partly attributed due to uncertainty in the metrology methodology. The original specifications were based on measurements under laboratory controlled conditions and the use of highly accurate laser interferometry. They were not determined with the store support assembled in the test section.

It is recommended that the metrology measurements are repeated within five year intervals. Improved methods to measure the translational and rotational movements should also be investigated.

7. References

1. *Store Support Checkout - Commissioning 1999.pdf*. In *ASE Working Notes*.
2. Manovski, P. and O'Connor, P. (2007) *Store Model Support Set Point Accuracy Check. Internal DSTO Document*.
3. Skarolid, R. (2008) *Store Model Support Repair*. *ASE Site Visit Notes*.
4. *TWT Mechanical Systems Operation and Maintenance Manual*. ASE/704381TP01,
5. *TWT User's Guide*. ASE/704303TP01,
6. *Store Support Checkout Data Mar-2013.xls*. (2013).
7. *Test Section / Model Support Section Assy, ASE Assembly Drawing 802353*. (2000).
8. *Store Support Checkout Results Mar-2013.xls*. (2013).

Appendix A: ASE2000LX Calibration Curves

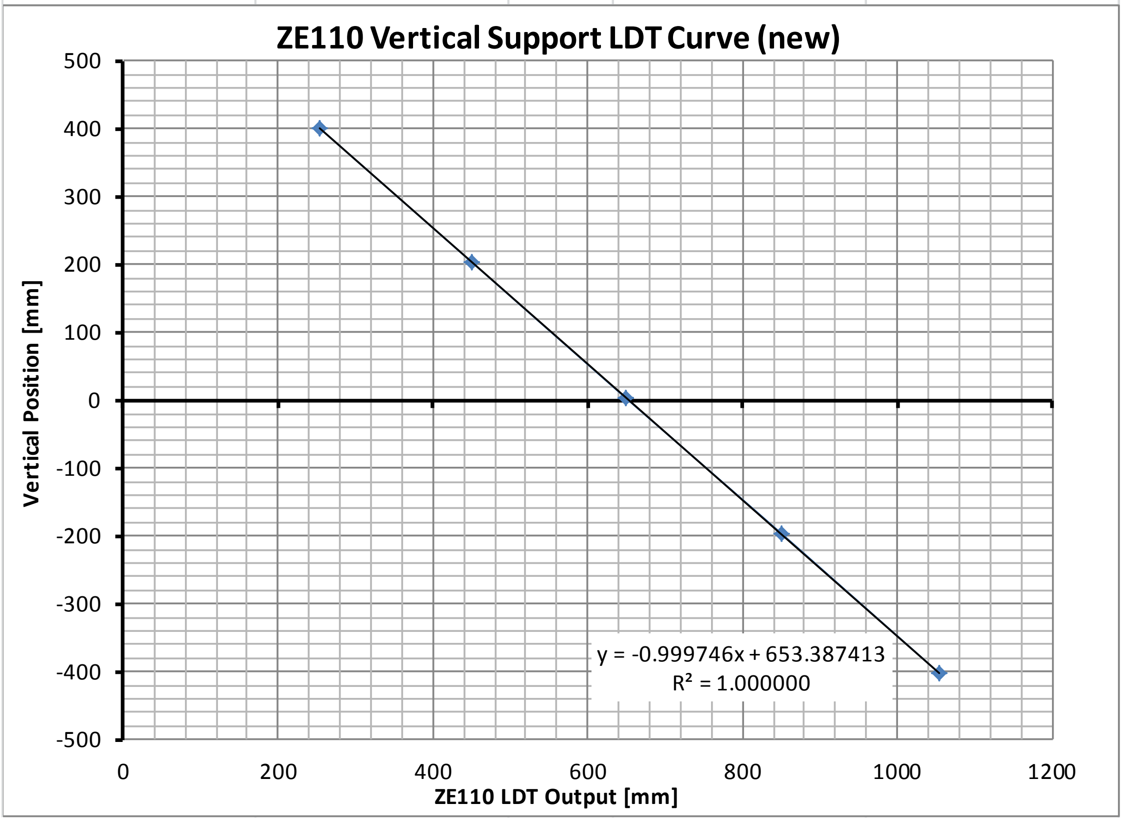
A.1. Main Support Strut Vertical LDT Curve (ZE110)

Curve Name:	**ZE110**
Curve Description:	**Vertical LDT**
ZE110_OFF:	**0.00**

Old LDT Values	
x	**y**
254.217896	400.083282
294.217896	360.083282
354.228912	300.063293
454.239014	199.995117
554.316284	99.958024
654.343201	-0.000126
754.391113	-100.020523
854.426392	-199.946808
954.482727	-300.021149
1014.493770	-360.049072
1054.493770	-400.049072

New LDT Values	
x	**y**
253.0	400.45
450.0	203.50
650.0	3.55
850.0	-196.40
1055.0	-401.34

Comments: Based on SS Checkout Results taken by JC / POC on 27/02/2013
(Run 2543)
Offset of 0.805 corrected, no span correction applied
Normalised for whole 'x' values



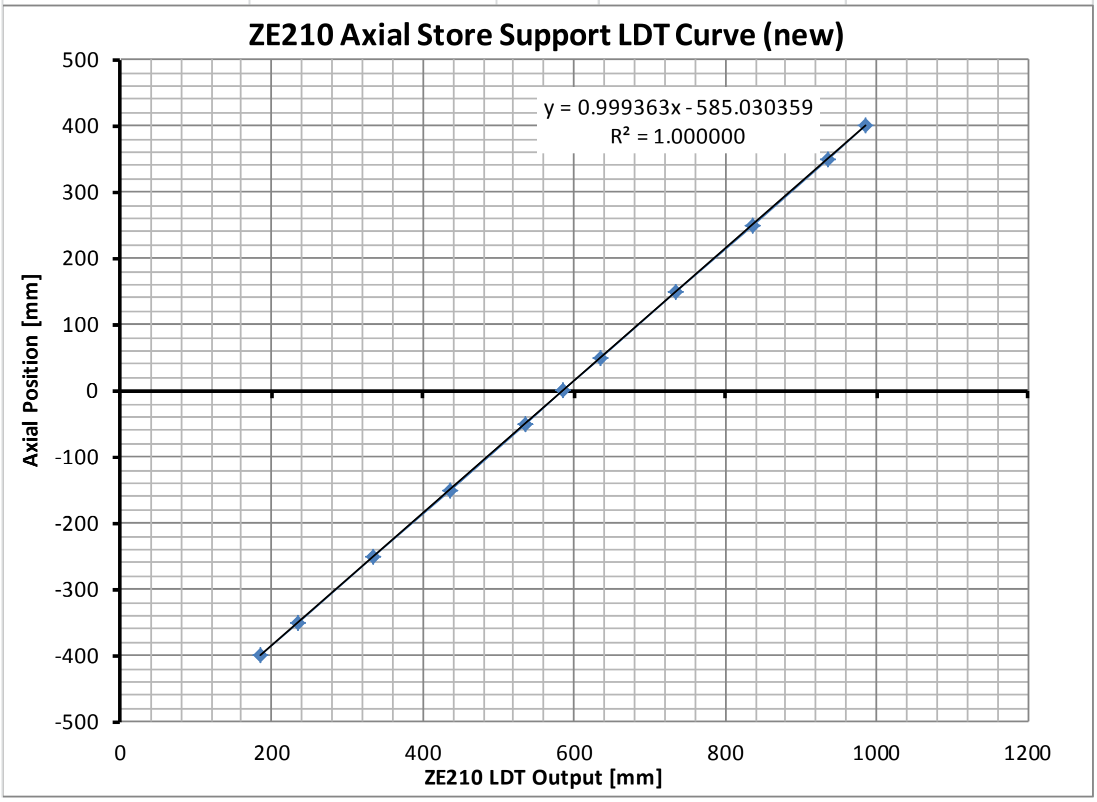
A.2. Store Support Axial LDT Curve (ZE210)

Curve Name:	**ZE210**
Curve Description:	**Axial LDT**
ZE210_OFF:	**201.00**

Old LDT Values	
x	**y**
185.229996	-400.079193
235.229996	-350.079193
335.200012	-250.050934
435.190002	-149.950485
535.239990	-49.958111
585.289978	0.016350
635.330017	50.026642
735.469971	149.914276
835.630005	249.933319
935.840027	350.140564
985.840027	400.140564

New LDT Values	
x	**y**
185.0	-400.30
335.0	-250.39
535.0	-50.52
585.0	-0.55
635.0	49.42
835.0	249.29
986.0	400.19

Comments: Based on SS Checkout Results taken by JC / POC on 26/02/2013
(Run 2542)
Offset of 0.15 corrected, no span correction applied
Normalised for whole 'x' values

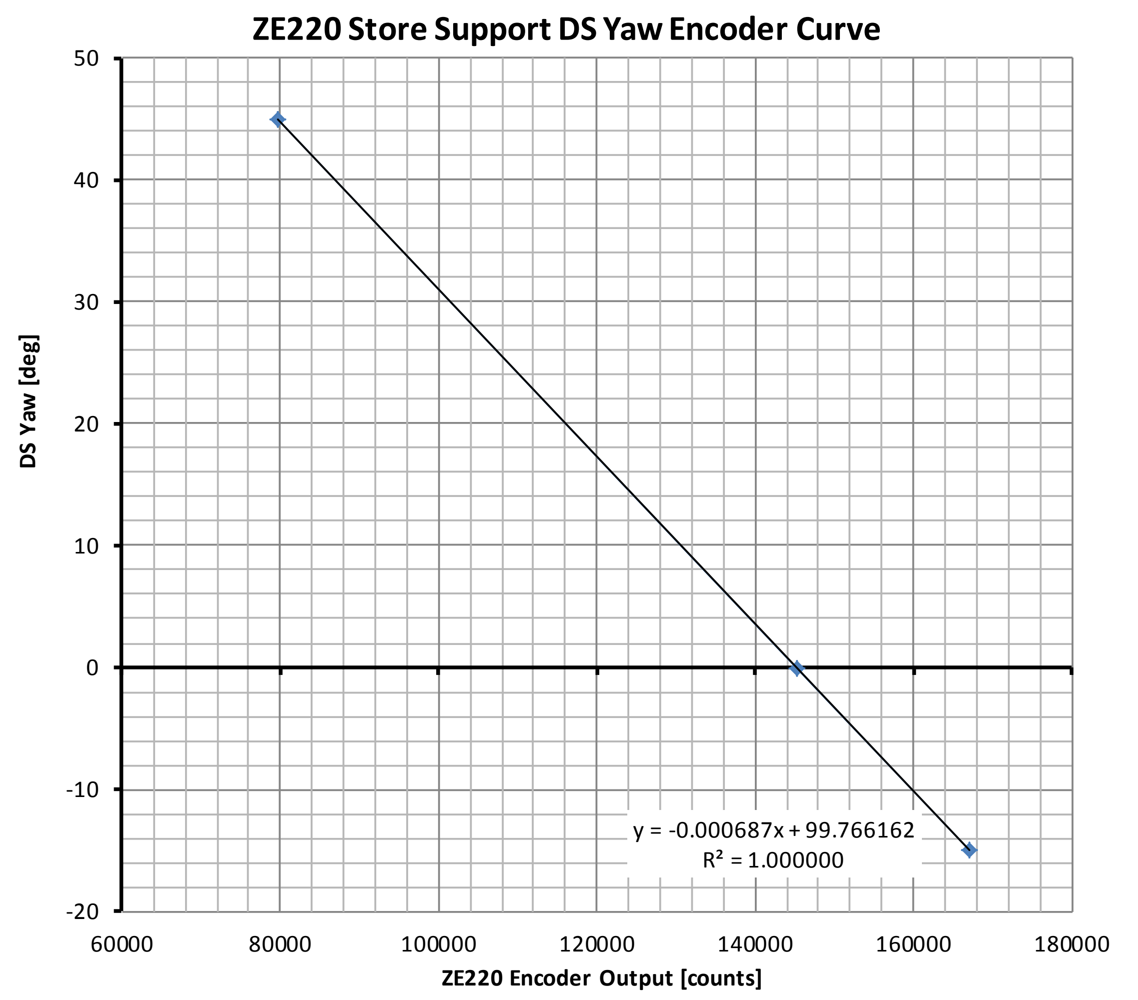


A.3. Store Support Downstream Yaw Encoder Curve (ZE220)

Curve Name:	ZE220
Curve Description:	DS Yaw
ZE220_OFF:	0.00

Current Encoder Values	
x	y
79759.000000	45.000000
145295.000000	0.000000
167140.328000	-15.000000

Comments: Unchanged



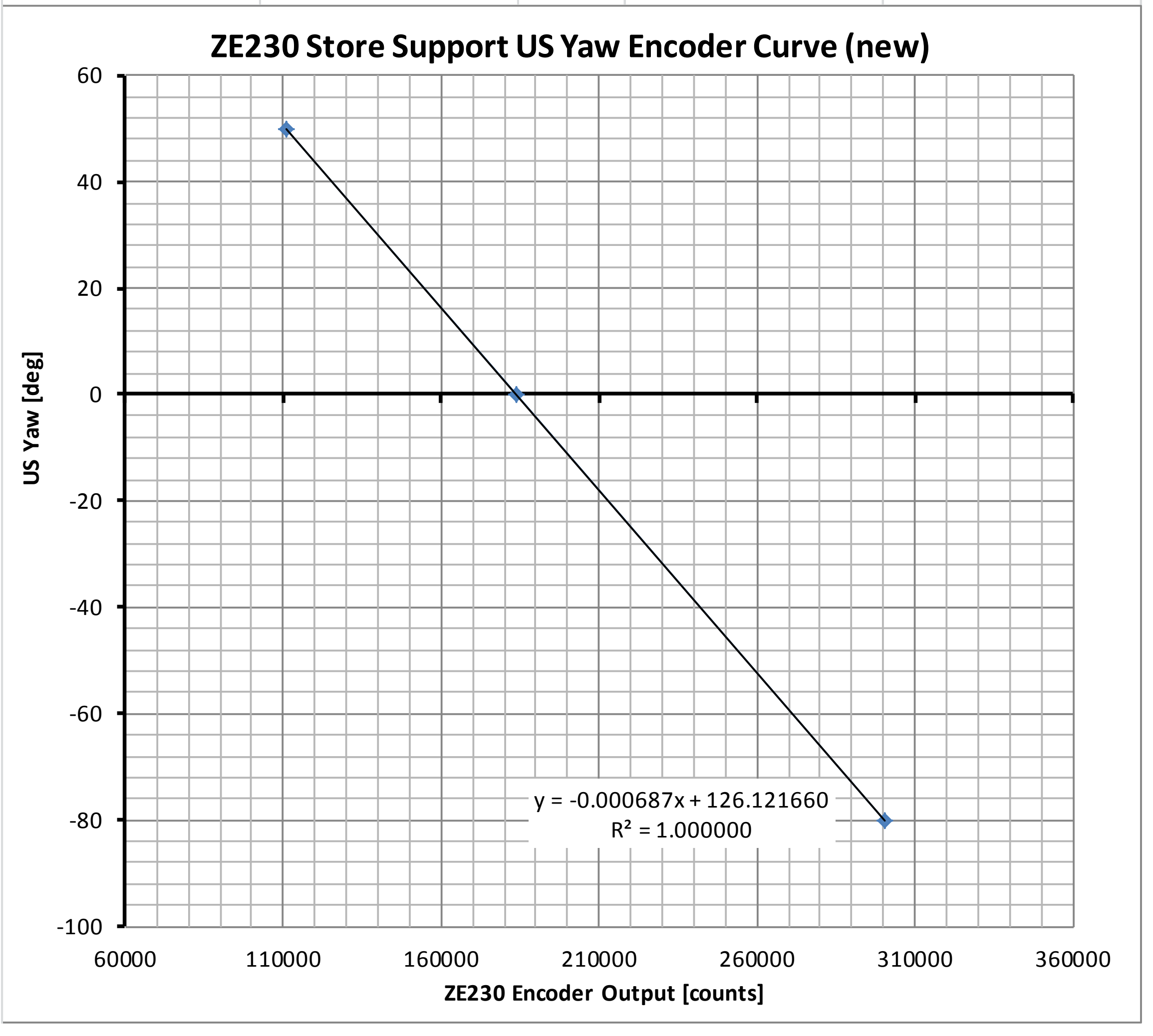
A.4. Store Support Upstream Yaw Encoder Curve (ZE230)

Curve Name:	**ZE230**
Curve Description:	**US Yaw**
ZE220_OFF:	**0.00**

Old Encoder Values	
x	**y**
110860.197667	50.000000
183677.978667	0.000000
300186.415667	-80.000000

New Encoder Values	
x	**y**
110604.0	50.00
183422.0	0.00
299930.0	-80.00

Comments: Based on SS Checkout Results taken by JC / POC on 15/03/2013
(Run 2546)
Offset of 0.176 corrected, no span correction applied
Normalised for whole 'x' values

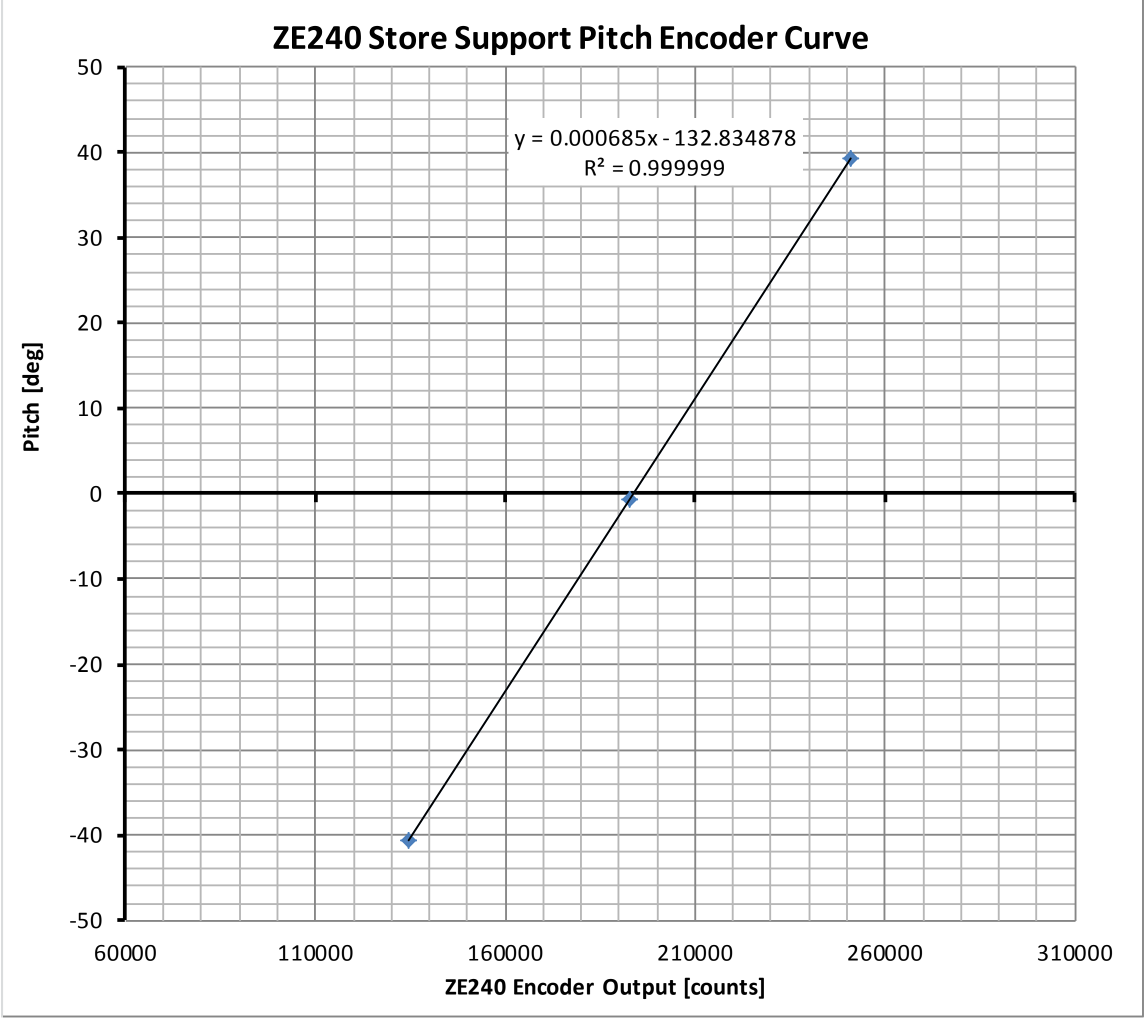


A.5. Store Support Pitch Encoder Curve (ZE240)

Curve Name:	**ZE240**
Curve Description:	**SS Pitch**
ZE240_OFF:	**0.00**

Old Encoder Values		**New Encoder Values**	
x	**y**	**x**	**y**
134644.776000	-40.530000	135659.0	-40.000
192899.000000	-0.680000	194023.0	0.000
251153.224000	39.320000	252386.0	40.000

Comments: Based on SS Checkout Results taken by JC / POC on 04/03/2013
(Run 2544)
Offset of 0.14 corrected, no span correction applied
Normalised for whole 'x' values

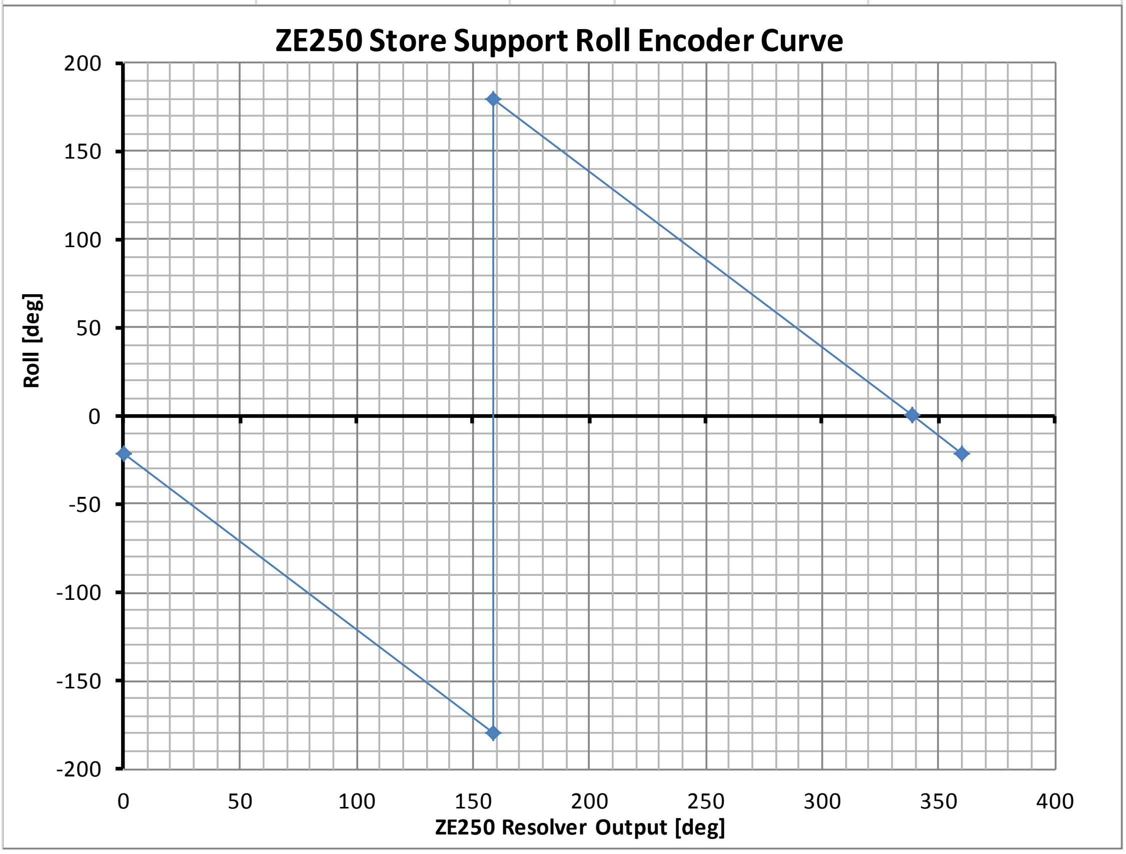


A.6. Store Support Roll Resolver Curve (ZE250)

Curve Name:	ZE250
Curve Description:	SS Roll
ZE240_OFF:	270.00

Current Resolver Values	
x	y
0.000000	-20.923000
0.000100	-20.923200
159.076800	-179.999900
159.076900	-180.000000
159.077000	179.999900
339.076800	0.000010
339.076900	0.000000
339.077000	-0.000100
359.999900	-20.893000

Comments: Unchanged



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19. ABSTRACT
The Defence Science and Technology Organisation operates a transonic wind tunnel which has a six degree of freedom store support system. This support system enables models under test to be translated and rotated in the test section to predefined positions and orientations. The accuracy of the translational and rotational readings from the store support system must be checked periodically to ensure that they are within acceptable uncertainty limits, and therefore provide quality assurance for test clients. This document details metrology measurements that were conducted during February and March 2013 on the store support together with subsequent results and adjustments applied to the associated calibration curves.