804000 Aircraft Scale Press

Aircraft Scale Calibration and Measurement Capability Using a Morehouse 804000 Press

This paper will describe our calibration process, including the calculations of our Calibration and Measurement Capability (CMC), as it appears on our scope of accreditation. We will cover the repeatability of a common aircraft scale as delivered directly by the manufacturer, along with the repeatability of the same scale, after Jackson Aircraft Weighing Systems (JAWS) made modifications to improve its performance and functionality. Anyone making force measurements can use these instructions as a guide for force CMC calculations using secondary standards, as defined by ASTM E74.

Morehouse Instrument Company

A Paper by

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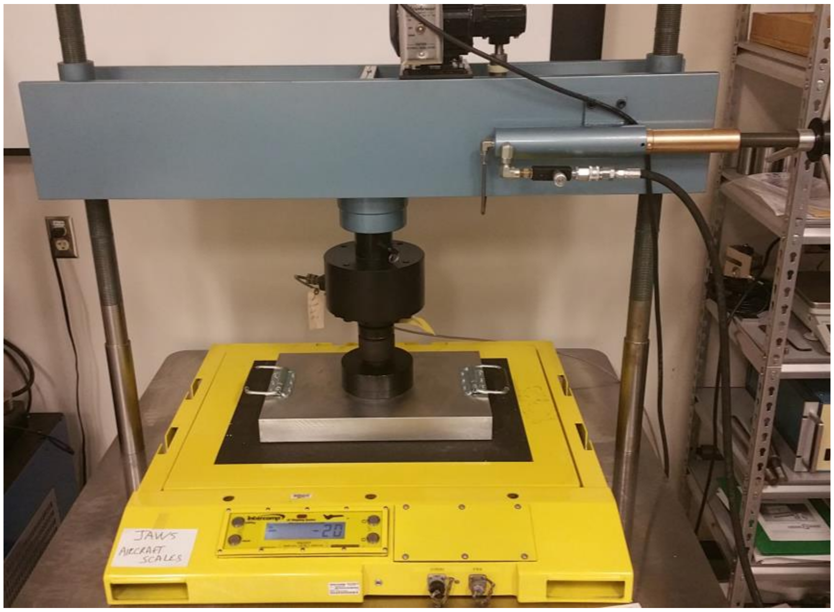
1. INTRODUCTION

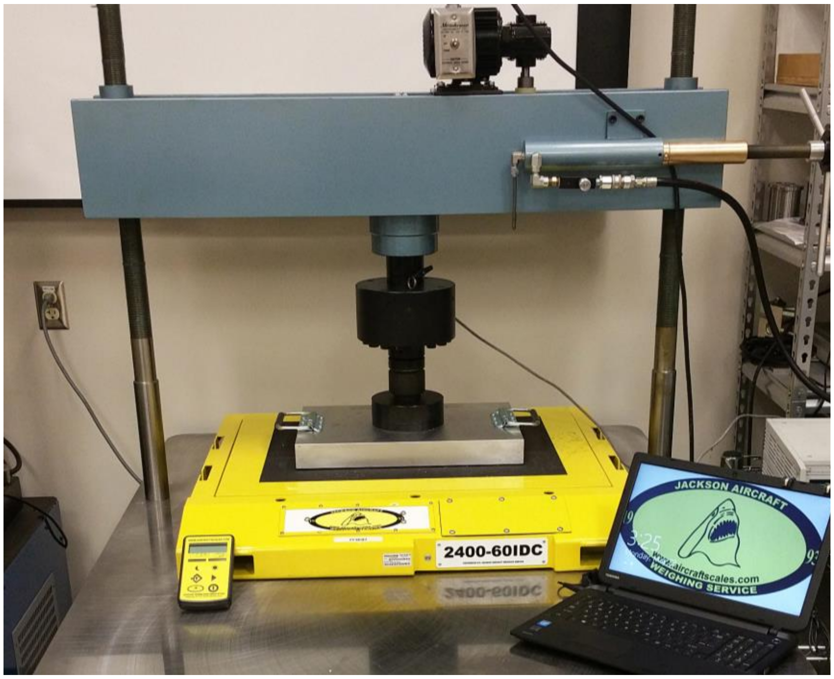
Morehouse has manufactured various force presses since the 1950s. Several press models have been manufactured for calibrating aircraft and truck scales. However, until now, commercial calibration service using these presses has not been offered. The decision was made, in early 2016, to build a Morehouse 804000 aircraft scale force press for "in house" use and to become accredited for the calibration of aircraft and truck scales.

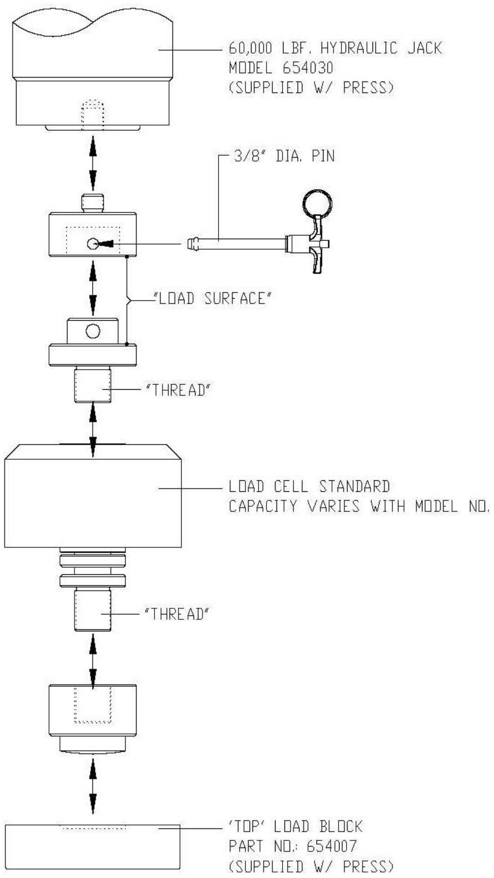
The CMC calculated with the standard, as delivered, Common Aircraft Scale with the 804000 press was 18 lbf throughout a 2,000 lbf through 60,000 lbf range. The CMC calculated for the JAWS upgraded scale varied between 2 and 4.7 lbf throughout the same range.

2. Test Pictures



Morehouse 804000 with Common Aircraft Scale





Morehouse 804000 with Common Aircraft Scale modified by Jackson Aircraft Weighing

3. Equipment List

The equipment used on the Common Aircraft Scale CMC analysis was as follows:

Force Transfer Standard used - Morehouse 804000 press
Reference Secondary Standard - Morehouse Ultra Precision 100K load cell, calibrated with deadweight primary standards known to within 0.0016 %
Indicator – HBM DMP 40
Adapters - Morehouse Accessories and Adapters for the 804000 press (see diagram in the picture above)
UUT – Intercomp AC30-60 with Internal Readout

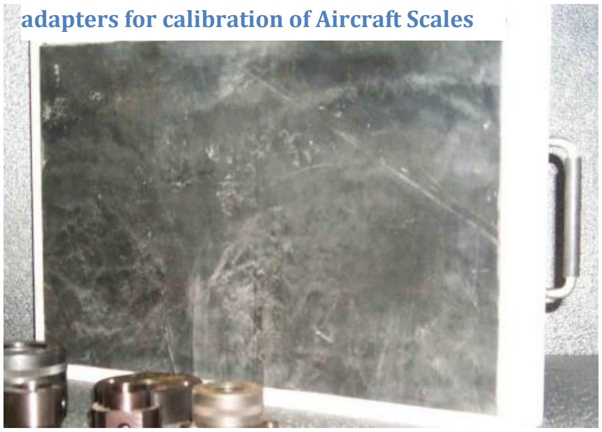
The equipment used on the modified Common Aircraft Scale CMC analysis was as follows:

Force Transfer Standard used - Morehouse 804000 press
Reference Secondary Standard - Morehouse Ultra Precision 100K load cell, calibrated with deadweight primary standards known to within 0.0016 %
Indicator – HBM DMP 40
Adapters - Morehouse Accessories and Adapters for the 804000 press (see diagram below)
UUT – Intercomp AC30-60
UUT Readout - JAWS wireless M2400 system

Morehouse rubber pad to simulate an aircraft tire was placed on top of the scale for calibration.

Part # P0000203

Morehouse recommended accessories and adapters for calibration of Aircraft Scales



4. Calibration and Measurement Capability

What is Calibration and Measurement Capability (CMC)? If a laboratory is accredited to ISO/IEC 17025, CMC is required to be calculated and is typically found on a non-testing laboratory's scope of accreditation. CMC is used to express the laboratory's measurement capability. The International Laboratory Accreditation Cooperation (ILAC) and the International Bureau of Weights and Measures (BIPM) defines CMC as the calibration and measurement capability available to customers under normal conditions. This means that the CMC represents a process of frequent measurement made by the laboratory on a regular basis. In this example, we are going to discuss how to calculate a CMC for the measurement process of calibrating a 60,000 lbf aircraft weighing scale.

The ILAC Procedure P-14 section 6.4 requires that contributions such as the resolution of the Unit Under Test (UUT) be included in the uncertainty per point value reported on the certificate of calibration. EURAMET, the European Association of National Metrology Institutes, CG4 v2.0 Uncertainty of Force Measurements also requires the resolution of both the standard and the UUT to be reported as standard contributors. The per point analysis consists of the UUT resolution and the CMC of our standard (which includes the resolution of the reference). When a full uncertainty analysis per ILAC P-14 is performed, as required by ISO/IEC 17025, the CMC (Calibration and Measurement Capability) is derived and reported to the end user.

Morehouse Measurement Uncertainty Calibration and Measurement Capability Worksheet

START ON THIS SHEET AND FILL IN ONLY LIGHT GREY BOXES

SECTION 1 DATA ENTRY			NOTE: ONLY ENTER INFORMATION IN LIGHT GREY BOXES
Laboratory	Morehouse		
Technician Initials	HZ		All information entered must converted to like units.
Date:	5/22/2016		This spreadsheet is provided by Morehouse Instrument Company
Range	2K-60K		It is to be used as a guide to help calculate CMC
Standards Used Ref and UUT	S/N 556633A UUT S/N 0423PR12003		
Resolution UUT	2	LBF	This is the resolution of the Unit Under Test you are Using for the Repeatability Study (What you are testing)
REFERENCE STANDARD INFORMATION			
ASTM E74 LLF *	1.926	LBF	* This is your ASTM E74 LLF Found on Your ASTM E74 Report. It will be converted to a pooled std dev (drop down for non ASTM)
Resolution of Reference	0.24	LBF	This should be found on your calibration report.
Temperature Spec per degree C %	0.0015%		This is found on the load cell specification sheet. Temperature Effect on Sensitivity, % RDG/100 F
Max Temperature Variation per degree C of Environment	1		During a typical calibration in a tightly controlled the temperature varies by no more than 1 degree C.
Morehouse CMC	0.0016%		This is the CMC statement for the range calibrated found on the certificate of calibration. Leave blank if entering Eng. Units
Miscellaneous Error	0	%	This can be creep, side load sensitivity or other known error sources. Enter and select Eng. Units or %
Conv Repeatability Data To Eng. Units	NO		

	Ref Standard Stability				Temperature Effect
	FORCE APPLIED	Change From Previous %	Interporlated 0	Actual LBF	0.000015
1	2000.00	0.0050%	0.10	0.1	0.03
2	5000.00	0.0050%	0.10	0.25	0.075
3	10000.00	0.0050%	0.25	0.5	0.15
4	20000.00	0.0050%	1.00	1	0.3
5	30000.00	0.0050%	1.50	1.5	0.45
6	40000.00	0.0050%	2.00	2	0.6
7	50000.00	0.0050%	2.50	2.5	0.75
8	60000.00	0.0050%	3.00	3	0.9
9					
10					
11					
12					

Repeatability of JAWS Modified Intercomp AC30-60

	Applied	Run1	Run2	Run3	Run4	Average	Resolution	STD DEV	CONVERTED
1	2000.00	2000	2000	2000	2000	2000	1	0.00000000	0
2	5000.00	5000	5000	5000	5000	5000	1	0.00000000	0
3	10000.00	10000	10000	10000	10000	10000	1	0.00000000	0
4	20000.00	20002	20002	20002	20002	20002	1	0.00000000	0
5	30000.00	30004	30004	30004	30004	30004	1	0.00000000	0
6	40000.00	40004	40004	40004	40006	40004.5	1	1.00000000	1
7	50000.00	50004	50006	50004	50006	50005	1	1.15470054	1.15470054
8	60000.00	60004	60006	60004	60004	60004.5	1	1.00000000	1
9									
10									
11									
12									
						Avg Std Dev of Runs		0.64549722	0.64549722

Ref Laboratory Uncertainty Per Point					MUST SELECT
Force	%	Eng. Units	Conv %	Force	% or Eng.
2000	0.0016%		0.000016	2000	%
5000	0.0016%		0.000016	5000	%
10000	0.0016%		0.000016	10000	%
20000	0.0016%		0.000016	20000	%
30000	0.0016%		0.000016	30000	%
40000	0.0016%		0.000016	40000	%
50000	0.0016%		0.000016	50000	%
60000	0.0016%		0.000016	60000	%
	0.0016%		0.000016		%
	0.0016%		0.000016		%
	0.0016%		0.000016		%
	0.0016%		0.000016		%

Morehouse Measurement Uncertainty Calibration and Measurement Capability Worksheet

Several tabs in this workbook were created to help with the following:

ASTM E74 Calibration and Measurement Capability (CMC) worksheet
Repeatability and Reproducibility (R & R) worksheet
ILC to Calculate En Ratios – This can be used to satisfy ISO 17025 section 5.9 b.
CMC Summary Worksheet – This uses a slope equation to interpolate expanded uncertainty (U) for any point within the loading range.

All Calibration and Measurement Capability (CMC) used for comparison tests was calculated using the Morehouse Measurement Uncertainty Calibration and Measurement Capability Worksheet. This sheet uses a combination of ASTM E74-13a annex, ISO 17025 and A2LA Document R205 to calculate measurement uncertainty. The measurement uncertainty contributors were accounted for as follows:

UUT Contributors

Repeatability of UUT in 804000 Press Using a Per Point Analysis
Resolution of UUT – The standard resolution of the Common Aircraft Scale is 10 lb, the JAWS upgraded scale was set at 2 lbf

Reference Standard Contributors

Reproducibility – For this, we use the ASTM LLF, which is a pooled standard deviation
Reference Standard Resolution
Reference Standard Short Term Stability since both tests were conducted within 2 months of one another and a value of 0.005 % was used for both tests
Environmental Factors
Single test point Repeatability and Reproducibility study conducted 5 – 10 times

5. The Reference Standard & UUT

A Morehouse Ultra Precision Load Cell, calibrated using the Morehouse Force Calibration Laboratory's 120,000 lbf Dead Weight Primary Standard Force Machine, was used as the reference standard. The measurement capability of the load cell was characterized using the following uncertainty contributors:

This Calibration Data is Certified Traceable to the United States National Institute of Standards & Technology

INTERFACE Load Cell, SERIAL NO. 556633A
60000.00 LBF Compression Calibrated to 60000.00 LBF
HBM DMP 40, SERIAL NO. 111320025

Calibration is in Accordance with ASTM E74-13
Ascending Compression DATA

Applied Load	Deflection Values Per ASTM Method 8.1B Interpolated Zero			Deviation From Fitted Curve			Values From Fitted Curve
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	
LBF	mV/V	mV/V	mV/V	mV/V	mV/V	mV/V	mV/V
1000	-0.04188	-0.04188	-0.04188	-0.00002	-0.00002	-0.00002	-0.04186
6000	-0.25120	-0.25122	-0.25121	0.00003	0.00001	0.00002	-0.25123
12000	-0.50243	-0.50245	-0.50246	0.00004	0.00002	0.00001	-0.50247
18000	-0.75368	-0.75372	-0.75371	0.00002	-0.00002	-0.00001	-0.75370
24000	-1.00490	-1.00496	-1.00494	0.00003	-0.00003	-0.00001	-1.00493
30000	-1.25615	-1.25620	-1.25618	0.00000	-0.00005	-0.00003	-1.25615
36000	-1.50735	-1.50740	-1.50738	0.00001	-0.00004	-0.00002	-1.50736
42000	-1.75853	-1.75859	-1.75855	0.00003	-0.00003	0.00001	-1.75856
48000	-2.00970	-2.00977	-2.00972	0.00006	-0.00001	0.00004	-2.00976
54000	-2.26088	-2.26096	-2.26091	0.00007	-0.00001	0.00004	-2.26095
60000	-2.51215	-2.51221	-2.51216	-0.00001	-0.00007	-0.00002	-2.51214

The following polynomial equation, described in ASTM E74-13 has been fitted to the force and deflection values obtained in the calibration using the method of least squares.

response = A0 + A1(load) + A2(load)^2

Where: **A0** 1.47181237E-5
A1 -4.18747775E-5
A2 9.2916073E-14

load = B0 + B1(response) + B2(response)^2

Where: **B0** 3.51577262E-1
B1 -2.38807224E+4
B2 1.26604536E+0

The following values as defined in ASTM E74-13 were determined from the calibration data.
Lower Limit Factor, LLF 1.926 LBF
Standard Deviation 0.0000336 mV/V
Class A Loading Range 1000.00 TO 60000.00 LBF

Morehouse Instrument Co., Inc.
1742 Sixth Ave., York, PA 17403
Phone 717/843-0081

- Resolution of reference standard: 0.24 lbf

- ASTM E74 LLF (Converted to a pooled standard deviation): 1.926 lbf

- Temperature effect on zero for the reference standard: 0.0015 % of rated output per 1° change in temperature

- CMC of 120,000 lbf Dead Weight Primary Standard Force Machine: 0.0016 %

- Stability of 0.005 % was used for both tests.

The UUT Contributors

- The standard resolution of the Intercomp AC30-60 is 10lbf; the upgraded scale was set at 2 lbf.

- Repeatability, characterized per point

6. CMC with Intercomp AC30-60

The major contributions from the UUT are resolution and repeatability.
On this test, the standard resolution of the Common Aircraft Scale was set at the factory to 10 lb. We tested repeatability by running the same test points throughout the range and repeating the measurements 4 times.

Resolution UUT	**10**	LBF

We took this information, along with the reference data, and ran everything through the Welch-Satterthwaite equation. This equation is used to calculate an approximation of the effective degrees of freedom of a linear combination of independent sample variances, also known as the pooled degrees of freedom.

Measurement Uncertainty Budget Worksheet									
Laboratory	Morehouse								
Parameter	FORCE	Range	2K-60K	Sub-Range					
Technician	HZ	Standards Used							
Date	3/14/2016								
Uncertainty Contributor	Magnitude	Type	Distribution	Divisor	df	Std. Uncert	Variance (Std.	% Contribution	u^4/df
Reproducibility Between Techs	3.16227766	A	None	0.000	1				
Repeatability Between Techs	0	A	Normal	1.000	18	000.00E+0	000.00E+0	0.00%	000.0E+0
Repeatability	5.7735E+0	A	Normal	1.000	3	5.77E+0	33.33E+0	78.71%	370.4E+0
Standard Deviation	802.5000E-3	A	Normal	1.000	200	802.50E-3	644.01E-3	1.52%	2.1E-3
Resolution of UUT	10.0000E+0	B	Resolution	3.464	200	2.89E+0	8.33E+0	19.68%	347.2E-3
Environmental Conditions	150.0000E-3	B	Rectangular	1.732	200	86.60E-3	7.50E-3	0.02%	281.3E-9
Stability of Ref Standard	250.0000E-3	B	Rectangular	1.732	200	144.34E-3	20.83E-3	0.05%	2.2E-6
Ref Standard Resolution	240.0000E-3	B	Resolution	3.464	200	69.28E-3	4.80E-3	0.01%	115.2E-9
Miscellaneous Error									
Morehouse CMC	160.0000E-3	B	Expanded (95.45% k=2)	2.000		80.00E-3	6.40E-3	0.02%	
			Combined Uncertainty (u_c)=			6.51E+0	42.35E+0	100.00%	370.7E+0
			Effective Degrees of Freedom			4			
			Coverage Factor (k) =			2.78			
			Expanded Uncertainty (U) K =			18.07	0.18068%		
Slope Regression Worksheet									
	Applied	Run 1	Run 2	Run 3	Run 4	Average	Std. Dev.	Ref CMC	LBF
1	10000.00	9990.00	10000.00	10000.00	9990.00	9995	5.7735	0.0016%	0.16
Repeatability (Of Error)			Average Standard Deviation of Runs			5.773503			

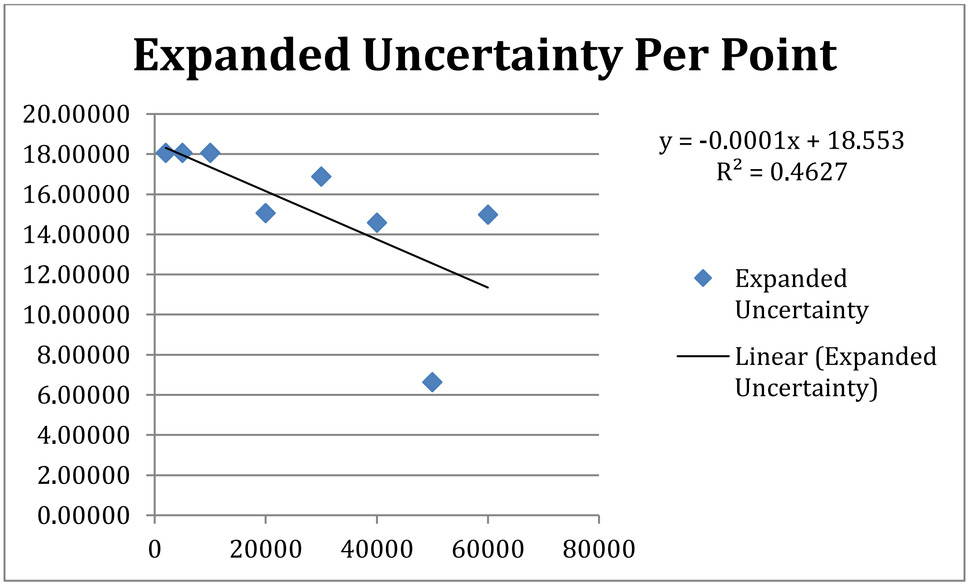
Welch-Satterthwaite Equation showing a coverage factor of 2.78 is needed for 95 % confidence

The above picture represents the 10,000 lbf test point on the scale. This same equation was run on each test point we recorded throughout the range. Determining the coverage factor for calculating the expanded uncertainties in a t-distribution requires establishing the total degrees of freedom. In a t-distribution, the variability and spread of the data around the mean depends on the degrees of freedom. In other words, a smaller sample size with fewer degrees of freedom can represent a lower amount of information about the population and provides higher uncertainty. By determining the degrees of freedom and mean, the coverage factor for the 95 % confidence level can be established. When independent variables are analyzed, the degrees of freedom of the combination of variables are not simply the sum of degrees of freedom for individual estimates. Methods such as the one developed by Welch-Satterthwaite must be used to make a more realistic estimate of the total degrees of freedom.

CMC per point summary for Common Aircraft Scale

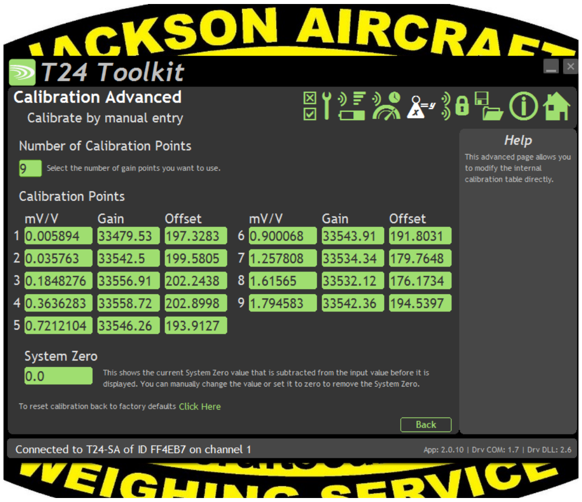
Applied	Expanded Uncertainty	Expanded Uncertainty %
2000	18.06170	0.90309%
5000	18.06232	0.36125%
10000	18.06828	0.18068%
20000	15.07051	0.07535%
30000	16.89374	0.05631%
40000	14.58693	0.03647%
50000	6.64434	0.01329%
60000	14.98072	0.02497%

Expanded Uncertainty Graph



Note: Expanded Uncertainty in the figure above did not necessarily change linearly by increasing load. The trend in the graph above was observed partly because the standard deviation of the repeatability observed at the 50,000 lbf test point was 0. All other points varied by +/- 10 lbf between runs. The R-squared value is very low. R-squared, also known as the coefficient of determination, is a statistical measure of how close the data are to the fitted regression line. In summary, a low R-squared number means that our line formula is only going to explain 46.27 % of the possible points, on average, within the measurement range.

7. CMC with Common Aircraft Scale with JAWS Modification



For this test, the resolution of the upgraded Intercomp scale was set to 2 lb using the JAWS software. We linearized the scale using the software (screenshot pictured left). Then, we tested repeatability by running the same test points throughout the range and repeating the measurements 4 times.

Resolution UUT	2	LBF

More information about JAWS can be found here.

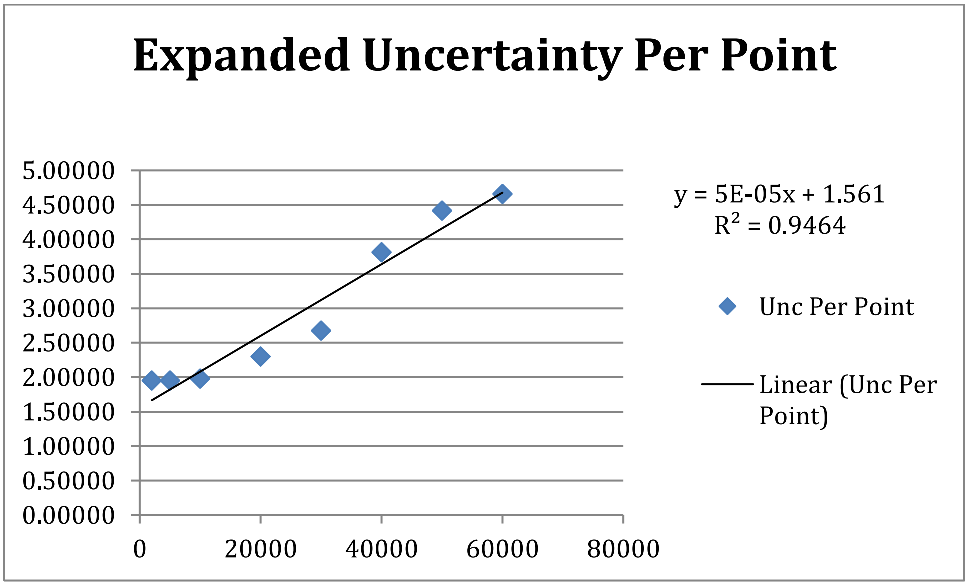
Measurement Uncertainty Budget Worksheet for Intercomp with JAWS modification									
Laboratory	Morehouse								
Parameter	FORCE	Range	2K-60K	Sub-Range					
Technician	HZ	Standards Used							
Date	5/22/2016								
Uncertainty Contributor	Magnitude	Type	Distribution	Divisor	df	Std. Uncert	Variance (Std. Uncert^2)	% Contribution	u^4/df
Reproducibility Between Techs	0	A	None	0.000	1				
Repeatability Between Techs	0	A	Normal	1.000	8	000.00E+0	000.00E+0	0.00%	000.0E+0
Repeatability	000.0000E+0	A	Normal	1.000	3	000.00E+0	000.00E+0	0.00%	000.0E+0
Standard Deviation	802.5000E-3	A	Normal	1.000	200	802.50E-3	644.01E-3	63.33%	2.1E-3
Resolution of UUT	2.0000E+0	B	Resolution	3.464	200	577.35E-3	333.33E-3	32.78%	555.6E-6
Environmental Conditions	150.0000E-3	B	Rectangular	1.732	200	86.60E-3	7.50E-3	0.74%	281.3E-9
Stability of Ref Standard	250.0000E-3	B	Rectangular	1.732	200	144.34E-3	20.83E-3	2.05%	2.2E-6
Ref Standard Resolution	240.0000E-3	B	Resolution	3.464	200	69.28E-3	4.80E-3	0.47%	115.2E-9
Miscellaneous Error									
Morehouse CMC	160.0000E-3	B	Expanded (95.45% k=2)	2.000		80.00E-3	6.40E-3	0.63%	
			Combined Uncertainty (u_c)=			1.01E+0	1.02E+0	100.00%	2.6E-3
			Effective Degrees of Freedom			392			
			Coverage Factor (k) =			1.97			
			Expanded Uncertainty (U) K =			1.98	0.01983%		
Slope Regression Worksheet									
	Applied	Run 1	Run 2	Run 3	Run 4	Average	Std. Dev.	Ref CMC	LBF
1	10000.00	10000.00	10000.00	10000.00	10000.00	10000	0.0000	0.0016%	0.16
Repeatability (Of Error)			Average Standard Deviation of Runs			0.000000			

Welch-Satterthwaite Equation showing a coverage factor of 1.97 is needed for 95 % confidence

CMC per point summary for Common Aircraft Scale with JAWS Modification

Applied	Expanded Uncertainty	Expanded Uncertainty %
2000	1.95263	0.09763%
5000	1.95548	0.03911%
10000	1.98255	0.01983%
20000	2.29970	0.01150%
30000	2.67618	0.00892%
40000	3.81469	0.00954%
50000	4.41841	0.00884%
60000	4.66153	0.00777%

Expanded Uncertainty Graph



Note: Expanded Uncertainty is now much closer to a linear trend. It appears that the modifications by Jackson Aircraft Weighing Systems have greatly improved Expanded Uncertainty linearity.

8. Modification and Upgrade Notes From JAWS

JAWS (Jackson Aircraft Weighing Systems) removed all the Common Aircraft Scales primary indication and built up a module that trims the load cells. A RAD wireless module was introduced, which then trimmed out the corner weights in accordance with T.O.33K6-4-3058-1. All 4 cells were adjusted to a determined point, using a proprietary method and setting points.

The JAWS modified module and upgraded onboard power allowed the cells to respond at a lower mV/V response rate. The Common Aircraft Scales cells are large truck-type cells; their initial response was not stable nor repeatable, especially in the lower weight and voltage ranges. JAWS applied a different schedule of voltages, gain, and offsets, called "progressive linear calibration," the same process JAWS used for the Scaled Composites, Stratolaunch space delivery scale system. Several runs were made, along with subsequent adjustments, and additional readings were taken.

After several on-site tests in Florida, JAWS forwarded the upgraded Common Aircraft Scales scale directly to Morehouse Instrument Company for additional unbiased traceable testing. The scale was tested and calibrated at Morehouse via live Internet connection with Morehouse personnel. An initial calibration was set, and no re-trim, offset or gain adjustments were made; the scale was left to run as set. JAWS feels that there can still be additional progress made to the Common Aircraft Scale unit, but just how much better and just how to measure its worth versus the effort are the questions that need to be answered.

The Morehouse run for determination of the viability of the JAWS modification was conducted independently without JAWS being present and without any inputs. Morehouse personnel conducted all testing to industry standards and recorded their findings for the application.

Screen Grab from JAWS software showing a reading of 60,004 with 60,000 lbf applied

9. CONCLUSION

The JAWS upgraded Common Aircraft Scale became an excellent scale for Morehouse to test and resubmit our CMC to A2LA. Our initial CMC was issued with a CMC of around 18 lbf. The new CMC for calibrating scales is 2.5 lbf for 1,000 lbf through 25,000, and 4.7 lbf for 25,001 through 60,000.00. The JAWS modification allowed Morehouse to use an actual scale to calculate CMC. We could have opted to use a very good load cell, though the opinion was that the best instrument should be one that we expect to calibrate in our machine. The JAWS modification improved repeatability by a factor of 5, improved resolution at 2 lbf instead of 10 lbf, and allowed linearization of points, which reduced bias.

Written by Henry Zumbrun – Morehouse Instrument Company

References:

ASTM E74-13a titled Standard Practice of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machine

JCGM 100:2008 Evaluation of measurement data — Guide to the expression of uncertainty in measurement

ILAC P-14 ILAC Policy for Uncertainty in Calibration

Appendix.

RAW DATA

Applied	Run 1	Run 2	Run 3	Run 4
2000.00	1990.0	2000.0	2000.0	1990.0
5000.00	4990.0	5000.0	5000.0	4990.0
10000.00	9990.0	10000.0	10000.0	9990.0
20000.00	19990.0	20000.0	19990.0	19990.0
30000.00	29990.0	30000.0	30000.0	29990.0
40000.00	39990.0	40000.0	39990.0	39990.0
50000.00	49990.0	49990.0	49990.0	49990.0
60000.00	59990.0	59990.0	59990.0	59980.0

Common Aircraft Scale Raw Data, Resolution 10 lb

Applied	Run 1	Run 2	Run 3	Run 4
2000.00	2000.0	2000.0	2000.0	2000.0
5000.00	5000.0	5000.0	5000.0	5000.0
10000.00	10000.0	10000.0	10000.0	10000.0
20000.00	20002.0	20002.0	20002.0	20002.0
30000.00	30004.0	30004.0	30004.0	30004.0
40000.00	40004.0	40004.0	40004.0	40006.0
50000.00	50004.0	50006.0	50004.0	50006.0
60000.00	60004.0	60006.0	60004.0	60004.0

Common Aircraft Scale with JAWS modification, Resolution 2 lb