Fourth International Symposium on Strain Gauge Balances
San Diego, California May 10-13, 2004

Recent Developments and Status of the Langley Single Vector Balance Calibration System (SVS)

Shirley M. Jones
Ray D. Rhew
NASA Langley Research Center
Hampton, Virginia 23681

The Langley Research Center (LaRC) Single Vector Balance Calibration System (SVS) was first introduced in 2000 by Peter Parker. The SVS combines the Design of Experiments (DOE) methodology with a novel load application system. Since that time three systems have been designed and developed with different load range capabilities (ranging from 2 pounds to 3,000 pounds). Approximately fifteen balances have been calibrated and their data compared to conventional techniques. This paper will present results of these comparisons, based on the mathematical models and accuracies, and discuss differences that were observed. In addition, changes in the implementation of the initial load schedules developed using DOE will be highlighted. One of the principles behind DOE is randomization. The initial loading schedules used to date have been randomized in the traditional DOE sense but not for repeat calibrations or experiments. Implementation of this randomization within blocks and its impact on data quality will be reviewed. Areas of potential future development will be presented which include changes in the centers to include loads with the force position system in the pure error estimates.

I. Introduction

The SVS is truly innovative in regards to two concepts: first, the system calibrates a force balance using a single vector and second, it harnesses the capabilities of experimental design or Design of Experiments (DOE) that renders a complete calibration using 64 purposeful points. The objectives, to provide a calibration system that enables the efficient execution of a formal experimental design, be relatively inexpensive to manufacture, require minimal time to operate, and provide a high level of accuracy in the setting of the independent variables, leads to achieving the goal of an accurate mathematical model to estimate the aerodynamic loads from measured balance responses. See reference 1 for more details.

The combination of the SVS and DOE reduces the calibration time for a standard calibration (determination of a 6x27 model) from 3-4 weeks for 729 points down to 2-3 days for 64 points. Figure 1 shows the SVS hardware components, which consist of a non-metric positioning system, a force positioning system, a two and three-axis angular measurement system, and calibrated weights. The non-metric positioning system rotates the force balance about the three axes. A multiple degree of freedom load positioning system utilizes a novel system of bearings and knife edge rocker guides to maintain the load orientation, regardless of the angular orientation of the balance. The load system, combined with the angular manipulation of the balance, allows the uni-directional load to be used to produce three force vectors and three moment vectors, with respect to the balance moment center. Due to its simplicity the SVS has fewer components than a points to test for curvature and estimate pure error. Table 1 displays the 64 calibration points for the UT-59 balance. The full-scale design loads are: Normal Force 400 lbs; Axial Force 40 lbs; Pitch Moment 1,200 in-lbs; Roll Moment 200 in-lbs; Yaw Moment 300 in-lbs; Side Force 100 lbs.

Block 1							Block 2						
Load Point	NF	AF	PM	RM	YM	SF	Load Point	NF	AF	PM	RM	YM	SF
	(lbs)	(lbs)	(in-lbs)	(in-lbs)	(in-lbs)	(lbs)		(lbs)	(lbs)	(in-lbs)	(in-lbs)	(in-lbs)	(lbs)
1	0	0	0	0	0	0	38	0	0	0	0	0	0
2	-170	-16	509	-85	127	-40	39	400	0	0	0	0	-90
3	-168	-17	505	84	126	-45	40	0	0	0	0	0	100
4	-170	-16	-509	85	-127	-40	41	0	0	0	0	300	100
5	170	-16	-509	-85	-127	40	42	-400	0	0	0	0	0
6	-170	16	509	85	127	-40	43	0	40	0	0	0	0
7	-168	17	-505	84	-126	-45	44	-400	0	-1200	0	0	0
8	168	-17	-505	84	-126	45	45	0	0	0	0	0	0
9	-168	17	-505	-84	126	45	46	-400	0	0	0	0	90
10	170	16	509	85	-127	-40	47	400	0	1200	0	0	0
11	-170	-16	509	85	-127	40	48	400	0	0	-200	0	0
12	-170	16	-509	-85	-127	-40	49	-400	0	0	200	0	0
13	0	0	0	0	0	0	50	0	0	0	0	0	0
14	-168	-17	-505	-84	-126	-45	51	-400	0	0	0	0	-90
15	0	0	0	0	0	0	52	0	0	0	0	0	-100
16	168	17	-505	84	126	-45	53	400	0	0	0	0	90
17	-168	17	505	84	-126	45	54	400	0	-1200	0	0	0
18	-168	-17	-505	84	126	45	55	0	0	0	0	-300	100
19	170	16	-509	85	-127	40	56	-400	0	0	-200	0	0
20	168	-17	505	-84	126	45	57	0	0	0	0	300	-100
21	168	-17	-505	-84	126	-45	58	-400	0	1200	0	0	0
22	170	-16	-509	85	127	-40	59	0	-40	0	0	0	0
23	170	-16	509	-85	-127	-40	60	0	0	0	0	0	0
24	170	16	509	-85	127	40	61	0	0	0	0	-300	-100
25	-168	-17	505	-84	-126	45	62	400	0	0	0	0	0
26	170	16	-509	-85	127	-40	63	400	0	0	200	0	0
27	0	0	0	0	0	0	64	0	0	0	0	0	0
28	170	-16	509	85	127	40							
29	-168	17	505	-84	126	-45							
30	-170	16	509	-85	-127	40							
31	168	17	505	84	126	45							
32	-170	-16	-509	-85	127	40							
33	-170	16	-509	85	127	40							
34	168	17	505	-84	-126	-45							
35	168	17	-505	-84	-126	45							
36	168	-17	505	84	-126	-45							
37	0	0	0	0	0	0							

Table 1. Balance UT-59 64-Point Calibration Schedule

II. SVS Capabilities

At LaRC, there are three SVS calibration systems in use: a 250 lb. (based on largest single force that can be applied), a 500 lb., and a 3000 lb. (3K) system. The current SVS hardware inventory contains 19 templates (see figure 2 for template examples), which can be utilized to calibrate 30 balances as illustrated in table 2.

The SVS template, which is composed of specific load points for a particular balance, is mounted directly onto the balance fixture. If a new fixture must be fabricated, then the fixture and the template can be fabricated as one unit. The FPS is attached to the balance template by means of a flange. The FPS is composed of two rings, one riding on bearings (roll) inside the circumference of the other with no interference (which allows the applied weight to align with gravity), and a yoke connected to the outer ring by means of bearings (pitch) that allows the weight pan and load to move without interference from the pitching of the balance.

On the nose of the balance fixture is mounted an orthogonal 3 axis AOA package that indicates the balance's roll and pitch orientation. A 2-axis AOA package is mounted directly to the FPS to indicate the pitch and roll position of the FPS. A series of knife edges suspends the weight pan from the FPS (see figure 1). For each loading, the balance is brought to the negative normal position, the FPS is secured to the desired position on the template, then the balance is rotated to the pitch and roll position, the load and weight pan are attached to the FPS, and allowed to settle before the data is recorded. The load and weight pan are then removed, the balance is returned to the negative normal position, and the FPS is moved to the next position.

250 LB. and the 500 LB. Systems

In the LaRC inventory, approximately 107 balances with a normal force range from 25-250 lbs. could utilize the 250 lb. FPS and 135 balances with a normal force range from 35-500 lbs. could utilize the 500 lb. FPS. Both smaller stands are relatively identical except for their scale. Each stand consists of two precise, incremented turntables, attached to a backstop and a machine base, powered by rechargeable drill motors with a tethered controller. One turntable manipulates pitch and the other turntable manipulates roll, the combination of which allows the desired x, y, and z coordinates to be obtained. A rolling moment support bar along with a taper adapter acts to project the balance to prevent interference with the FPS. Figure 2 depicts these system components.

FBS

The Force Bracket System (in figure 3) is an alternative method to the FPS when sensitive loads are required. It is essentially a bracket that is mounted to the load template and then the specially made weights can be attached to each side of the bracket once the balance is positioned. The current load range is from 2 to 25 lbs. and there are three brackets: 2- 2 lbs. and 1-3 lbs.

Though the FBS was used to calibrate the CF4-3, the IR-15, and in +/- axial loading for the 2019D, it has the potential to be utilized by as many as 49 of the balances in the LaRC inventory that meet its load range criteria.

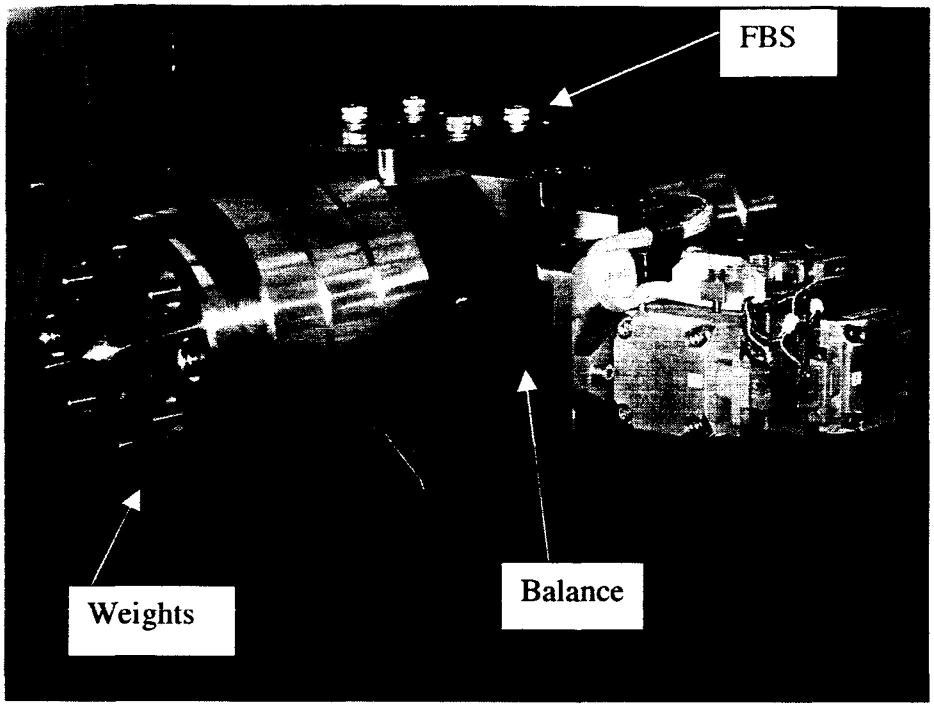

Figure 4. Force Bracket System (FBS)

3K System

The potential number of balances in the LaRC inventory with a normal force load range of 75-3000 lbs. that could utilize the 3K system is approximately 200. The 3K system (figure 5) operates in such a manner that the balance moment center is maintained at basically the same height therefore, the non-metric positioning system structure to achieve this constraint is very different from the 250 and 500 lb. systems. The 3K system consists of a massive freestanding steel base supporting a u-shaped structure that pivots like a swing, but retains its desired set point due to the gearbox, motor, and brakes. The u-shaped structure is attached to the flanged side of 2 shafts that pass through each of the u-legs and the base creating the pivot points. One side terminates in an in-line gearbox and pitch motor. A coupling is mounted to the u-structure and the balance is attached to the coupling at one end and at the other end the roll motor is mounted perpendicular to the balance. Both the pitch and roll motors are ac servos with ratios of 293 to 1 and100 to 1 respectively. The motors are controlled by digital servo drives with electric brakes, and a system of safety interlocks. The 3K FPS weighs approximately 85 lbs. and is lifted onto the balance fixture/SVS template by means of a hoist and then carefully moved into place using a ratcheting roller system that is built-into the 3K FPS. Currently, the 3K SVS system has been used to calibrate the Boeing 6176A and the UT65A balances.

Balance (Normal Force in lbs.)	Normal	Axial	Pitch	Roll	Yaw	Side
UT65A, SVS (800)	0.06	0.22	0.04	0.22	0.07	0.07
UT65A, Std. (800)	0.06	0.22	0.07	0.09	0.06	0.14
UT55, SVS (150)	0.01	0.09	0.05	0.18	0.09	0.04
UT55, Std. (150)	0.07	0.14	0.06	0.18	0.10	0.05
UT59A, SVS (400)	0.07	0.17	0.04	0.16	0.08	0.06
UT59A, Std. (400)	0.07	0.33	0.06	0.17	0.09	0.08
UT39A, SVS (150)	0.04	0.04	0.04	0.21	0.06	0.08
UT39A, Std. (150)	0.06	0.19	0.07	0.21	0.09	0.07
NTF107, SVS 250 (160)	0.04	0.04	0.03	0.10	0.05	0.04
NTF107, SVS 500 (160)	0.04	0.03	0.05	0.11	0.05	0.04
NTF107, Std. (160)	0.04	0.08	0.04	0.09	0.06	0.08
IR21, SVS (100)	0.22	0.10	0.17	0.27	0.11	0.23
IR21, Std. (100)	0.22	0.18	0.16	0.24	0.12	0.23
SS08ZR, SVS (100)	0.128	0.093	0.083	0.162	0.269	0.118
SS08ZR, Std. (100)	0.13	0.11	0.18	0.18	0.27	0.20

Table 4. Calibration Results from SVS and Conventional Technique

orientation, used for adjusting the applied load (reference 2) especially roll, was determined to be the main factor affecting the roll error anomaly.

Investigation of the yoke orientation on the roll component involved comparing the calibration matrices from the LaRC 729 to the SVS. The comparison revealed the normal squared on roll interaction was significantly different. This particular interaction is directly related to the yoke orientation and further to the position of the knife-edge system (see figure 1) relative to the balance moment center (BMC). Parameters impacting this position are dimensional measurements with respect to the BMC, and orientation determined by the 2-axis accelerometer system.

The dimensional measurements were reviewed as well as the procedure used for acquiring the measurements. These measurements, performed again with the same procedure, were within tolerance. However, the 2-axis accelerometer system was calibrated to determine if it was still within tolerance (2*std dev = 0.002 degrees) and it was not. Therefore, this system was removed from the calibration system and a re-positioning procedure was implemented (using levels that were part of the initial development) until the 2-axis accelerometer system accuracies are resolved. Subsequent calibrations with the levels using re-positioning have shown marked improvement in the roll error and general agreement with the LaRC 729 results.

VI. Summary

Development of the SVS has been a great improvement in the calibration of balances at LaRC. It produces calibration results that are more defendable statistically and in less time than the previous method. This paper has provided an update on the systems currently available for calibrations and touched on the calibration process itself. Also, issues and current development activities have been discussed that deal with the roll component and experiment design changes. Future enhancements such as adding temperature calibration capability are on hold as full implementation is currently the top priority.

VII. Acknowledgements

The authors would like to acknowledge several individuals associated with implementing the SVS at LaRC. First and foremost is the inventor Peter Parker. His patience with handing over the systems was and is very appreciated. Second, the employees at Modern Machine and Tool Company, Incorporated for their technical support in all phases of the development and implementation.

VIII. References

1) Parker, P.A.; Morton, M.; Draper, N.; Line, W.: A Single-Vector Force Calibration Method Featuring the Modern Design of Experiments. AIAA 2001-0170. January 2001.
2) Parker, Peter A.; Liu, Tianshu: Uncertainty Analysis of the Single-Vector Force Balance Calibration System. AIAA-2002-2792. January 2002.
3) Parker, Peter A.; DeLoach, Richard: Response Surface Methods for Force Balance Calibration Modeling. 19th ICIASF. August 2001.
4) Simpson, Jim; Landman, Drew; Rhew, Ray; Giroux, Rupert: Manual Balance calibration using Design Experiment Methods. 4th International Symposium on Strain-Gauge Balances. May 2004.