# SPECIAL-PURPOSE STRAIN-GAUGE BALANCE FOR ONE WING PANEL OF A WIND TUNNEL MODEL

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## 1. Introduction

Measurements of external aerodynamic load using a wind tunnel balance are based on the behavior of the balance as an elastic system. The balance transfers the load to a fixed support. Deformations of the balance caused by the load are measured using strain gauges applied at convenient measuring stations on the balance body.

Experimental Aerodynamics Department of the Military Technical Institute (VTI) designs, produces, calibrates and uses various strain-gauge-based electromechanical force transducers for measurements in wind tunnel tests (wind tunnel balances). Practical experience in this field has been gained for more than thirty years. A wide range of designs is in use, from one-component to six-componet internal and external balances. The majority of realized designs are monoblock balances, being built from single pieces of high-quality steel.

A special-purpose three-component wind tunnel balance was designed, built, calibrated and used for measurements of aerodynamic forces and moments on a wing panel of a particular wind tunnel model of a missile with slots on the body for storage of folded wings.

## 2. Design requirements

During balance design certain requirements had to be respected as much as possible:

– Desired load components had to be measured with sufficient accuracy;

– Changes in the angle of attack of the wing, relative to model body, caused by aerodynamic loads acting on the balance, had to be minimized;

– Geometry and location of measuring stations on the balance had to be selected so that sufficiently high levels of output signals could be obtained from measuring bridges; however, relative deformation at any location of a strain gauge was not to exceed 2000 μm/m;

– Satisfactory safety factors, defined as higher than 2 on the basis of equivalent normal stress (von Mises stress) relative to yield strength, had to be established on the critically loaded locations on the balance;

– Deformations of measuring stations caused by primary load components (load components measured at that particular balance stations) had to be more significant than deformations caused by secondary load components;

– If possible, strain gauges had to be applied symmetrically on the measuring stations, in order to provide the highest possible stability;

– The balance was to be calibrated with load configurations as similar as possible to those in the actual test conditions.

## 3. Wing balance design concept

The three-component strain gauge balance was required to measure normal force $Y$, hinge moment $N$ and bending moment $L$, Fig.1, without obstruction to crossflow through the slots.

The relevant load component, for the design of the balance was the normal force, Table 1. The monoblock (single piece) balance concept was selected for the balance. An analysis showed that the use of the Vascomax 350 steel, with high mechanical performances and good machinability was required.

The load range and available space constraints dictated that the balance be of the bending-beam type. Design concept with two parallel load-sensing flexures was selected because the characte-ristic of this type of the balance is that the angular deflection of the loaded balance around the hinge axis is very small. The two-flexure design also produced little or no obstruction to crossflow through the slots on model body.

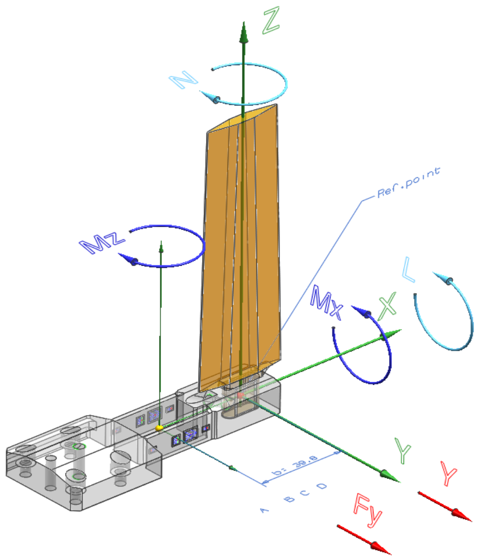


**Fig. 1.** Aerodynamic load which were measured.

## 4. Wing balance calibration concept

Any special-built single-use balance is being calibrated at the beginning of the wind tunnel test, usually when the balance is already installed in a model, and connected to the data acquisition system. This procedure ensures that the balance is calibrated in the conditions as similar as possible to the actual test conditions.

The wind tunnel data reduction software in VTI supports primarily the model of the relation between the loads and output signals of a multicomponent balance in which the output signals are expressed as functions of applied loads, [1]. Balances are calibrated using a modern “single-vector” technique that permits simul-taneous application of loads to more than one measuring element (component) of the balance, Fig.2. The idea behind this approach is that the loading configuration during calibration should be representative of the conditions in which the balance will be during a wind tunnel test.

An extensive calibration of the balance was performed, with about 280 datapoints, optimized for load configurations expected in the wind tunnel test. Calibration results confirmed the correct operation of the balance in this configuration. Achieved uncertaintes were very good both in terms of the maximum errors (P.Err.) and in the terms of standard deviations (Std.d.), Table 1 (*Fy*, *Mx* and *Mz* were physical measurement compo-nents, combined to form *Y*, *L* and *N*, while *F++* and *M++* were total force and moment loads).

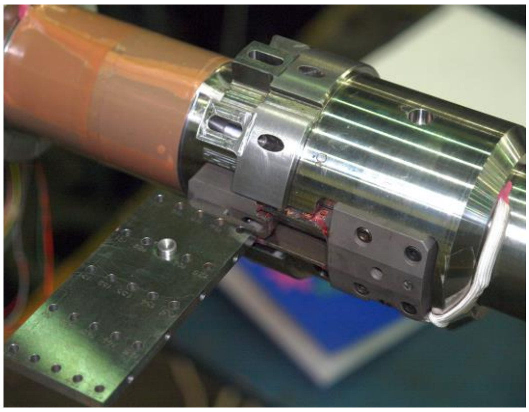

**Fig. 2.** Calibration of the balance.

**Table 1.** Summary results of the calibration

| BalanceComponent | *Fy* | *Mx* | *Mz* | *F++* | *M++* |
|---|---|---|---|---|---|
| Load range,N,Nm | 290 | 18.9 | 15.7 | 290 | 33.2 |
| Applied load,N,Nm | 270 | 17.5 | 13.4 | 270 | 17.5 |
| P.Err.[%] | –0.087 | –0.121 | 0.124 | 0.087 | 0.069 |
| Std.d.[%] | 0.032 | 0.044 | 0.040 | 0.032 | 0.025 |

Achieved accuracies compare well to the current requirements [1] for advanced strain gauge balances, which have been adopted by VTI as the guidelines for evaluating balance quality. The requirements call for standard deviations of the errors, computed from the back calculated calibration data, of approximately 0.05% of full range load for each component under all configurations of loads, which corresponds to an “accuracy” of about 0.1% of full scale design loads. For all components, the balance satisfies these requirements.

## 5. Conclusions

The balance satisfied the design and calibration requirements. Achieved accuracy, for 95% measu-rement certainty (equal to 2σ), was better than 0.1%FS for each component (target design accuracy was 0.2%FS). Wind tunnel test campaign confirmed the correct operation of the balance and a very good agreement was noted between test results obtained from the balance and the preliminary CFD calculations.

## References

[1] Recommended Practice for Calibration and Use of Internal Strain-Gauge Balances with Application to Wind Tunnel Testing, AIAA Standards, R-091-2003e, 2003