ASAT

MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

WIND TUNNEL INSTRUMENTATION TECHNIQUE

BALANCE DESIGN PROBLEMS

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ABSTRACT

The most important piece of instrumentation in a wind tunnel is the balance, which at present time normally is designed as an internal strain gage balance.

Since airplane performance can be evaluated only from precise force measurements in the wind tunnel and since performance is the ultimate goal of airplane development, the accuracy of the balance is a key problem in wind tunnel work.

The author describes a successful technology for balance design and fabrication. In order to avoid hysteresis and internal friction, a balance should be designed and fabricated from one single piece of metal. This leads to difficult fabrication methods which are avoided by the MBB technology to assemble the balance from pieces by an electron beam welding process. By a special heat treatment the original material behaviour is restored.

Sophisticated gage application methods and calibration methods contribute to an excellent balance accuracy and reliability. Especially the problem of temperature effects and temperature gradient compensation is discussed in the paper; an outlook on balance technology for cryogenic wind tunnels is given.

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1. INTRODUCTION

The quality of wind tunnel test results and their benefit to airplane development work or aeronautical research work depends to a high degree on the accuracy and reliability of the wind tunnels measuring instrumentation. Other parameters influencing the quality of the results are flow quality, the use of sophisticated models and the skill and experience of the wind tunnel test team.

Since in airplane development the majority of wind tunnel tests are force measurements with internal strain gage balances, these balances are a key problem in wind tunnel testing. In recent years considerable progress has been made in the art of balance design, fabrication and calibration. This progress was partly supported by the big improvements of electronic devices like amplifiers and digital voltmeters which allow to observe previously unknown effects.

Since internal balances are used for multi component force measurements in wind tunnels, in principle two main types of balances have been developed; the one-piece balance, fabricated from one single piece of metal, and balances built up from a number of parts. Normally the one-piece balance follows the double bending beam principle whereas the built up balance represents the floating frame principle.

Compared with the double bending beam one-piece balance the built up floating frame balance allows much more freedom in the design and in the adaptation of the measurement ranges to the requirements. Low interference is easier to obtain than with the one-piece design. On the other hand the built up balance suffers from a major problem, that is creep, friction and hysteresis produced by the screwed of wedged joints of the balance parts. This is such a difficult problem, that to my knowledge only one built up balance design could earn excellent commercial reputation, namely the well known Task Balance (now fabricated by the Able Company).

The problem of the joints is completely avoided by the one-piece balance design,normally a double bending beam design with a parallelogram spring arrangement between the bending points for longitudinal force measurement. This system is widely used with good results in most wind tunnels. The main shortcoming of this standard design is the complicated design and the difficult machining necessary to generate the parallelogram spring design out of a single piece of metal. Even with a very sophisticated design cuts are necessary which limit the stiffness and the strength of such a balance.

2. THE "WELDED BALANCE" TECHNOLOGY

Considerable efforts were undertaken at MBB Transport Division towards a balance technology which eliminates the friction and the hysteresis problems of the built up floating frame design as well as the low stiffness and the machining problems of the standard one-piece balance. A solution was found in the technology to build up the balance from several parts, which are integrated by electron beam welding, thus forming a one-piece balance without the machining restrictions of the standard design.

The electron beam welding technology is well established at MBB Transport Division for the fabrication of rocket fuel tanks and space sattelite structures.

Figure 1 shows a six component balance as an example of this technology. The design principle is shown in Figure 2. Front end and rear end, each machined from one piece of metal, are already aligned with fitting bolts. The parallelogram spring plates are machined simply from stock plate material. For maximum stiffness combined with high sensitivity the bending beams are resolved in 5-bar cages. The balance just after the welding process, fitting bolts not yet removed, is shown in Figure 3. The welding seam is clearly visible in this picture. The close up view (Figure 4) after mudblast treatment demonstrates the real one-piece appearance of the balance.

Further development led to the concept, to machine the internal surfaces only before welding; thus the structure is less sensitive against distortion during the welding process. Figure 5 shows the parts of the balance W 606 prior to the welding process and the finished balance is shown in Figure 6.

The technology was used for fabrication of a large six component balance for the German Dutch Low Speed Wind Tunnel (DNW), see Figure 7. Technical dates of this balance are:

Total Length:	1220 mm		
Diameter:	200 mm		
Force Capacity:	Normal Force	30000	N
	Side Force	12500	N
	Axial Force	12500	N
	Pitching Moment	11500	Nm
	Yawing Moment	9000	Nm
	Rolling Moment	9000	Nm

During several years of Airbus development testing this balance proved highly successful. Repeatability and resolution are excellent and hysteresis is practically non-existing. Useful accuracy of this balance is only limited by minor thermal effects. With standard strain gage balances these effects are hidden by scatter and hysteresis; in the case of the DNW balance these effects gave rise to some research in order to get an even better balance. Further research on these effects is pushed by the future use of cryogenic wind tunnels, where the thermal effects are much greater.

3. THERMAL EFFECTS OF STRAIN GAGE BALANCES

3.1 Effects due to homogeneous Temperature Change

Due to a homogeneous temperature change four different physical effects occur:

1. Thermal expansion of balance material
2. Change of strain gage resistance
3. Change of Youngs Modulus of balance material
4. Change of K-Factor of strain gage

A zero drift of the strain gage bridges results from the combination of effects 1 and 2, whereas a change in sensitivity results from the effects 3 and 4. Nevertheless these effects cause no real problem in balance fabrication and utilisation. Matching of gages to the balance material and carefully adjusted compensation resistors in the bridge circuits reduce these effects almost to zero for the conventional wind tunnel temperature range. For the large temperature range of the cryogenic tunnel these effects can be described and corrected by mathematical methods with satisfying accuracy.

3.2 Effects due to Temperature Gradients

Spatial and temporal temperature gradients in the balance structure are unavoidable due to temperature changes in wind tunnel operation. Due to distortion of the balance structure these gradients cause error signals especially in the axial force measuring system; correction of this effect is very difficult.

Figure 8 shows a principle sketch of a conventional axial force system (parallelogram system). In this figure it is assumed, that the temperature level in the outriggers partial length "ℓ_1" is increased, so thermal expansion increases this length by $\Delta\ell_1$. The dotted lines indicate the resulting distortion of the parallelogram system; the measuring spring 'B' produces an error signal. If F_A, F_B and F_C are the forces acting at the spring groups A, B and C, equilibrum equations can be formulated for the general case (different expansions $\Delta\ell$ at all four partial lengths ℓ):

Forces: $F_A + F_B + F_C = 0$ (No external force)

Expansions: $f_A - f_B = \Delta\ell_1 - \Delta\ell_3$

$f_B - f_C = \Delta\ell_2 - \Delta\ell_4$

where f_A, f_B and f_C are the distortions of the springs A, B and C. By introduction of the spring stiffnes Φ,

$\Phi_A = F_A/f_A$ etc.

the equilibrium equations can be combined to give the error force due to thermal gradients at the measuring spring 'B':

$$F_B = \Phi_B \cdot \frac{\Phi_A(\Delta\ell_3-\Delta\ell_1) + \Phi_C(\Delta\ell_2-\Delta\ell_4)}{\Sigma\Phi}$$

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Under the assumption of a symmetric design: $\Phi_A = \Phi_C = \Phi_P/2$ this converts to:

$$F_B = \frac{1}{2} \cdot \frac{\Delta\ell_3 - \Delta\ell_1 + \Delta\ell_2 - \Delta\ell_4}{1/\Phi_P + 1/\Phi_B}$$

For given length changes $\Delta\ell$ this equation tells, that the force error due to thermal effect F_B may be decreased by reducing the stiffnes Φ_P of the parallelogram springs and the stiffness Φ_B of the measuring spring.

Since for a good axial force signal as much as possible of the axial force should be concentrated on the measuring spring, the stiffness reduction should be concentrated on the parallelogram springs. Of course this effort is limited by the high stress in the parallelogram springs due to yawing moment.

The changes in partial length $\Delta\ell$ are directly proportional to the mean temperature change on these partial lengths. Fig. 9 shows an instrumentation of the axial force system outriggers with temperature sensors (platinum resistors). On each partial length three sensors are mounted; the combined signal of the three sensors is a measure of the mean temperature of this partial length. If all sensors are wired in a bridge circuit as indicated in Fig. 9, the output signal U_B of this bridge is directly proportional to the expression $(\Delta\ell_3 - \Delta\ell_1 + \Delta\ell_2 - \Delta\ell_4)$ in the equation above. So with a single additional measurement an excellent temperature gradient correction is possible.

For cryogenic wind tunnel balances this correction method almost certainly is not sufficient. Further improvement seems possible by integration of the axial force sensing element into the two parallelogram spring groups instead of placing it halfway between them in the conventional arrangement. Development of such configurations is under way at MBB and the Technical University of Darmstadt.

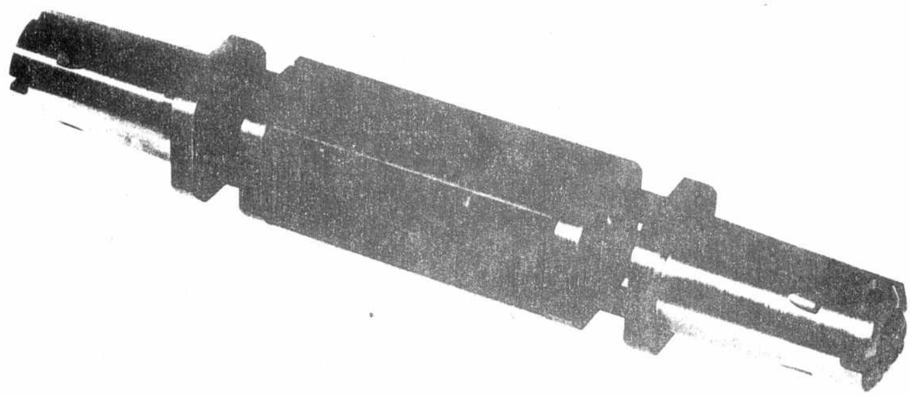

Fig.1. Six Component Balance W 64

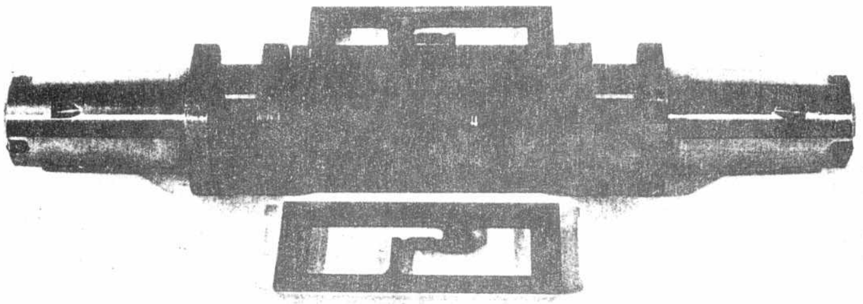

Fig.2. Balance prepared for Welding

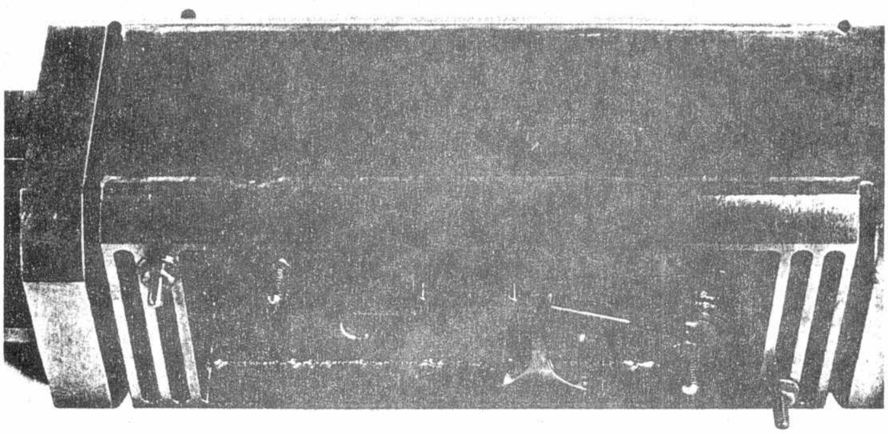

Fig.3. Balance after Welding Process
Fixture Bolts not yet removed

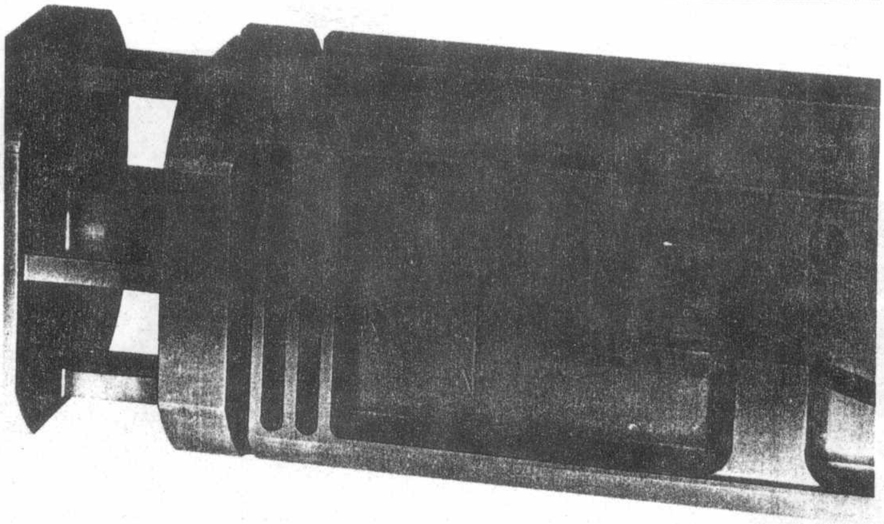

Fig.4. Close up of finished Balance
5-Bar Cage and Parallelogram

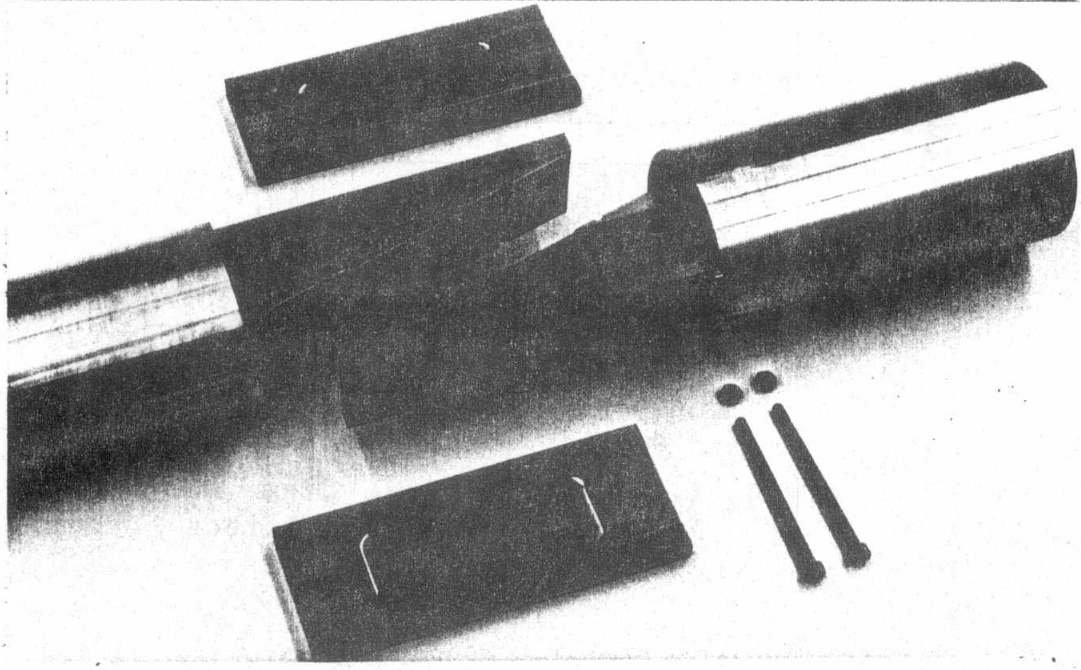

Fig.5. Parts of Balance W 606

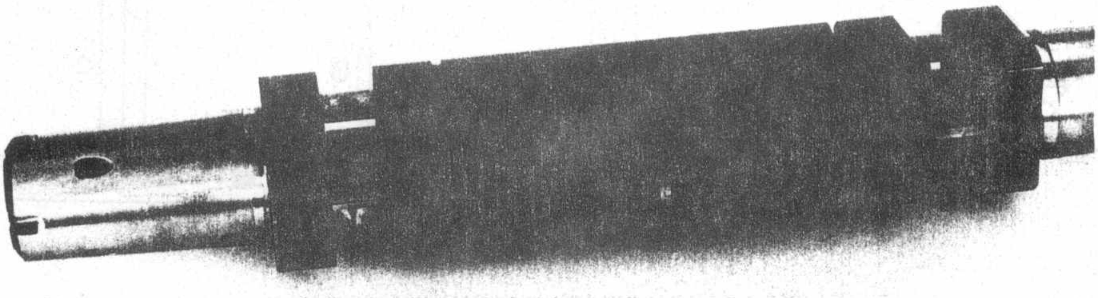

Fig.6. Finished Balance W 606

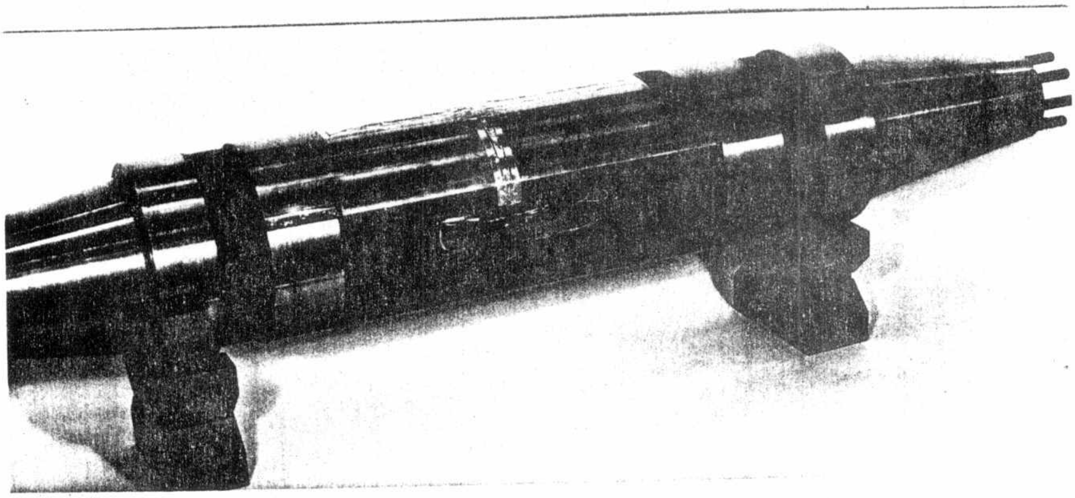

Fig.7. DNW-Balance W 605

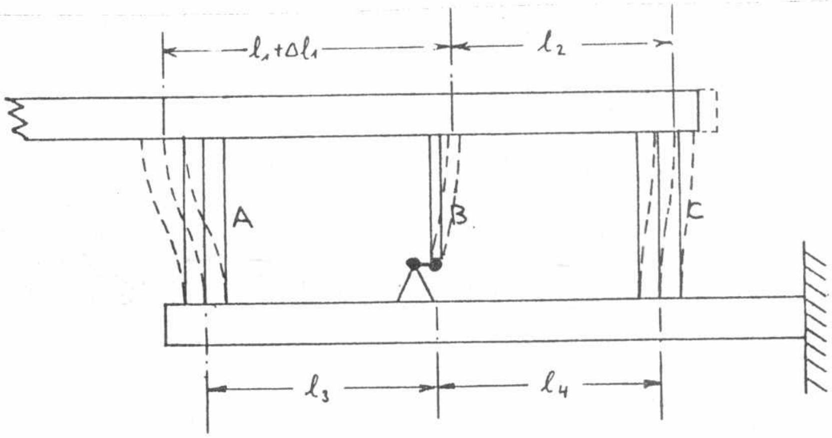

Fig.8. Axial Force System with Temperature Gradient Effect

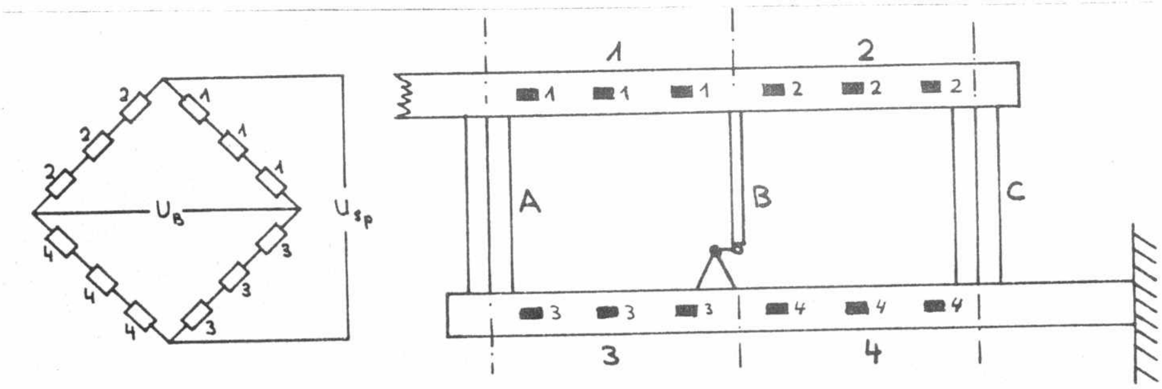

Fig.9. Sensor Instrumentation for Temperature Gradient Correction