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TITLE

A new balance and air-return line bridges for DNW-LLF models

B664 / RALD 2001

PERMISSION

AUTHORS	DATE	PP	REF
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DESCRIPTORS

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ABSTRACT

The DNW-LLF has bought a new internal balance to complete its range of large internal balances. This new balance was designed and manufactured by NLR (see figure 1). There were several reasons for investing in a new big internal strain gauge balance:

By specifying the load range equal to that of balance W608 the new balance is a full back up balance for the frequently used balance W608.

Furthermore this balance allows back to back testing of similar models in the DNW-LLF, increasing the effectiveness of the facility.

The new balance is smaller than balance W608 creating more space for other equipment such as for instance air line bridges. The new balance has a length of 700 mm and a diameter of 180 mm (inclusive shield).

Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

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B664 / RALD 2001

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* German Dutch Wind Tunnels

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- The new balance is smaller than balance W608 creating more space for other equipment such as for instance air line bridges. The new balance has a length of 700 mm and a diameter of 180 mm (inclusive shield).

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A NEW BALANCE AND AIR-RETURN LINE BRIDGES FOR DNW-LLF MODELS

B664 / RALD 2001

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SYMBOLS

a_i Accuracy coefficient of component 'i' [-]
Aij Linear coefficients [N/(mv/V), Nm/(mv/V)]
$Aijk$ Quadratic coefficients [N/(mv/V)^2, Nm/(mv/V)^2]
CD Aerodynamic Drag coefficient $CD = D/qS$ [-]
CL Aerodynamic Lift coefficient $CL = L/qS$ [-]
D Drag force in wind axis [N]
F_i Maximum load of a specific load component 'i' [N, Nm]
F_n Actual load acting on component 'n' [N, Nm]
$F_{n,\,max}$ Maximum load of load component 'n' [N, Nm]
L Lift force in wind axis [N]
q Dynamic pressure. [Pa]
Ri Output reading of the balance (i=1,…6) [mV/V]
S Wing Surface Area [m^2]
T_{model} Increase in the balance temperature at the model side of the balance [K]
T_{sting} Increase in the balance temperature at the sting side of the balance [K]
α Pitch angle [deg.]
β Yaw angle [deg.]
δ_i Root mean square averaged error of component 'i' [N, Nm]

Load designation

Load	Load	Description
F_1	F_x	Axial force
F_2	F_y	Side force
F_3	F_z	Normal force
F_4	M_x	Rolling moment
F_5	M_y	Pitching moment
F_6	M_z	Yawing moment

ABBREVIATIONS

BCM Balance Calibration Machine
FS Full Scale
FEM Finite Element Method
LLF Large Low-speed Facility
RALD 2000 Air-supply Line Bridge
RALD 2001 Air-return Line Bridge

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1 GENERAL

The DNW-LLF has bought a new internal balance to complete its range of large internal balances. This new balance was designed and manufactured by NLR (see figure 1). There were several reasons for investing in a new big internal strain gauge balance:

- By specifying the load range equal to that of balance W608 the new balance is a full back up balance for the frequently used balance W608.
- Furthermore this balance allows back to back testing of similar models in the DNW-LLF, increasing the effectiveness of the facility.
- The new balance is smaller than balance W608 creating more space for other equipment such as for instance air line bridges. The new balance has a length of 700 mm and a diameter of 180 mm (inclusive shield).

For the aerodynamic development of the A400M, Airbus utilizes several DNW facilities (DNW-LLF, DNW-NWB and DNW-LST). For the DNW-LLF A400M checkout model a new air line bridge system has been designed and manufactured. This new system (see figure 20) comprises an already existing air supply line bridge (RALD 2000) and a new air return line bridge (RALD 2001). The air-supply line system has a capacity of 12 kg/s at a pressure of 80 Bar and an air temperature of 343 K, and fits within a diameter of 0.44 meter. The new air-return line system has (also) a capacity of 12 kg/s at a pressure of 16 Bar and an air temperature of 263 K, and will fit into the DNW-LLF A400M check-out model. In general the power and size of the air motors used to provide the power for the propeller, dominate the scale of a powered full model. This leads to a relatively small model given the size of the facility. Implying the space for any air line bridge system is very limited.

2 BALANCE 664

2.1 Requirements

The goal was to make a balance with the load range of DNW-LLF internal balance W608 (size 1000 mm length, 224 mm diameter) and the size of DNW-LLF internal balance W616 (size 700 mm length, 150 mm diameter) a balance with a smaller load range. Nevertheless, the new balance should have an accuracy and repeatability that is equal to or better than that of balance W608. The load range of the balance is presented in table 1.
The accuracy is defined according to the following formula:

$$\delta_i \le \frac{1}{1000} \cdot |F_i| \cdot \left[a_i + \sum_{\substack{n=1 \\ n \ne i}}^{6} \left| \frac{F_n}{F_{n,\max}} \right| \right] \qquad (1)$$

The accuracy coefficients for W608 are given in table 2. In general the repeatability of the internal balance W608 is about 1/3 of its accuracy.
Further, the balance should function well with and without an air line bridge system mounted to it. This implies that the deflections of the new balance should be small. Small deflections imply only small displacements between the metric and non-metric flanges of the internal balance. This will allow the air line bridge system to follow this displacement without causing significant parasitic forces and moments. Balance W608 has a very good performance with air line bridges mounted to it. So the deflections should match that of balance W608.
Another challenge in the design was posed by the following two requirements. One, the balance should have a central bore (cable duct) through it. This bore in the balance has a tube inside it (that is mounted to the non-metric part of the balance). Two, the balance must have a heat insulating tube around the outside of the balance.
The inner tube is used to shield cabling that is crossing the balance. Note that the balance connectors are on the metric side of the balance. The outer heat insulation tube protects the balance against thermal effects caused by the airline bridge systems.
Also a requirement was the temperature behavior of the new balance. The balance should be able to cope with the typical temperature gradients and heating up and cooling down times of large model in an atmospheric wind tunnel. Ideally there should be no output caused by any of these effects.
Finally, the balance needed to be ready for operation within one year.

This new internal balance designated B664 was designed and manufactured by NLR, see figure 1.

2.2 Design

Balance B664 is designed following the approach that has been evolved during the last 20 years at NLR (Ref. [1]). In this approach the design process starts with a pre-design according standard handbook formulas (bending of beams) and ends with a Finite Element Method model of the balance. The Finite Element Method has been routinely used by NLR since 1990 in the design process of balances (Ref. [2]). Several FEM models have been built of B664 in order to optimize the design. The final FEM-model is based on SOLID elements and is a

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representative theoretical model of the balance. The results of this latter model are used for:

- the stress analysis (safety factor),
- calculation of the sensitivities and interactions,
- calculations of the stiffness and the deflection coefficients,
- determination of the load rhombi,
- analysis of the temperature effects.

2.2.1 Stress analysis

Balance B664 is not an extreme highly loaded balance. However, the central hole limits the design freedom significantly. Balance B664 is made from maraging steel grade 300. The required safety factor of 4 on yield gives a maximum allowed stress level of 454 MPa for all the load components simultaneously. There are 2^6 = 64 load combinations. Due to the symmetry of the balance, port/starboard and up-/down-stream, only 16 of the combinations are checked to satisfy the maximum stress level requirement. It turned out that the combination of $-F_x$, $+F_y$, $-F_z$, $-M_x$, $+M_y$, $+M_z$ is the most severe load combination. This combination yields a maximum Von Mises stress of 504 N/mm², see figure 2.

2.2.2 Sensitivity

The mesh or element division of the FEM model of the balance is such that in each location of a strain gage one element node is positioned. In these nodes the stress states are available for 6 separate applied load cases (F_x, F_y, F_z, M_x, M_y, M_z). Following Hooke's law the corresponding strains can easily be calculated. The appropriate combination of the strain results of 4 or 8 nodes, in a Wheatstone bridge formula, provides the output for the 6 load cases. In this way the sensitivities and interactions are calculated.
The results of the same nodes can be used to calculate the effect of a certain temperature distribution when the FEM model is loaded by a temperature gradient.

2.2.3 Deflections

From the FEM model of the balance also the nodal displacements can be extracted. These displacements can be used to calculate the relative displacement of the balance and the balance house (wind tunnel model). The same is possible for the balance and the inner tube. Figure 3 shows that the balance can function without fouling in a wind tunnel model with an inner bore of 186 mm.
Based on figure 4 it can be concluded that the central hole in the balance must be partly conical in order to avoid contact between the balance and the inner tube. The balance in combination with the inner tube has a foul detection. The theoretical deflection coefficients are given in table 3. Note that the diameter of the balance was increased with 20 mm, to 170 mm (exclusive shield). This was necessary to get close to the required deflection coefficient for pitching moment M_y.

2.2.4 Load Rhombi

The load envelope can be determined with load range formulas. In fact the load range formulas are stress monitoring equations and are also used as such. Except for the interfaces, the equations are based on the FEM model of the balance. In principle, each load range formula consists of six coefficients that must be multiplied with the absolute values of the respective actual loads to give stresses (Ref. [2]). The summation of these stresses must be smaller than a given stress level to give the load rhombi. The maximum allowed stress levels are based on the safety factor requirements. For each load component at least one formula is limiting the load range. The formulas are based on stress levels in the measuring sections of the balance, the main beams of the balance and the attachments.
The equations can be used for instance to derive the maximum single loads. However, in off-design situations the standard calibration results are not interpolated but extrapolated.

2.2.5 Temperature effects

Based on actual wind tunnel tests with balance W608 four temperature cases were specified. These temperature cases were used as input for the FEM calculations to verify temperature gradient effects on the new balance. The temperatures are defined at the 18 locations (spread over the balance) where the Pt100 temperature sensors are. The temperatures are given as an offset to the average balance temperature. The temperature cases represent typical temperature distributions for several wind tunnel test situations:

- RALD calibration,
- High dynamic pressure in wind tunnel,
- Civil aircraft without engine simulation,
- Civil aircraft with engine simulation.

The thermal distribution and the resulting thermal stresses are calculated for these four situations. Subsequently the resulting outputs from the strain gage bridges are calculated. For all the four temperature cases the output of all the 6 Wheatstone bridges is well below 1 µV.

The balance has two heat insulating covers each consisting of two halves. The covers are semi-permanent mounted on the balance. Calculations and some experiments pointed out that it was more favorable to have a high heat conductive shield material instead of an isolating material when the balance is used in combination with a RALD. Although it is not the sole purpose of the shield, it also functions as a protection sleeve.

2.2.6 Miscellaneous

The interfaces with the model and the sting are identical with the existing W616: a flange with 12 M20 bolts. The balance is exchangeable with DNW balance W608 by using two adapters (total length 1000 mm). Two additional adapters can be mounted to make the balance exchangeable with DNW balance W605 (total length 1257 mm). In this last configuration the balance is calibrated. In principle this build up of adapters accumulates the measuring uncertainties caused by the interfaces and the interface effects. However, because the adapters all have flange type interfaces on both sides, this effect is limited. (Ref. [1])

The balance body itself has provisions for future air line bridges smaller then RALD 2000, Ref. [4]). At this moment the balance can be used with the same air line bridges that are used on balance W608 by using the W608-B664 adapter set. These adapters have provisions for mounting the air line bridges in the same way as on balance W608.

2.3 Manufacturing

Despite the size of the balance the manufacturing process was more or less standard except for two items:

- Handling of the balance
- Oven issues.

2.3.1 Handling

The balance mass is about 100 kg. Therefore, special precautions had to be taken to handle and manipulate the balance, especially during the application of the strain-gauges. It is not only important to create a safe work situation but also a comfortable situation for the strain-gauge application engineer. This should not be underestimated because he is one of the most vital links in the balance manufacturing process. The application engineer can not compensate for a bad balance design but he can easily spoil a good balance design. Therefore it is important that the engineer has easy access to all the locations on the balance where instrumentation has to be placed. For this purpose a special stand was manufactured. With this stand it was easy to position the balance (pitch and roll) and to sit next to the balance and use a microscope and solder tools on the balance.

2.3.2 Oven Issues

The size of the balance demanded an extension of the existing oven. The door of the oven was removed and a cart was manufactured which could hold the heavy balance and extended the oven as well. With this cart it was possible to ride the balance into the oven.
Due to the extension and the large balance mass the oven capacity was not sufficient to produce the recommended temperature raise rate of 3-11°C per minute (Micro Measurements M-Bond 610). The maximum attainable rate was about 1°C per minute, measured on the balance. Despite the well-isolated cart and the fan in the oven, the temperature in the extension part of the oven was lower than in the oven itself. For this reason the balance was always positioned with the strain gauges to cure in the oven part. In addition the oven was programmed with the maximum temperature overshoot. To be able to post-cure the balance about 40°C above the curing temperature, the curing temperature was chosen at 135°C for 3 hours.

2.4 Calibration

B664 was calibrated in the BCM (Balance Calibration Machine) of the QinetiQ 5m wind tunnel. This calibration machine is used by DNW-LLF to calibrate their large internal balances. The characteristics of the balance are described using the following commonly used math model.

$$F_i = A_{ij} R_j + A_{ijk} R_j R_k \qquad (2)$$

The BCM allows 1st order calibration of pure loads. Since the math model only allows for a linear description of the 2nd order effects the following calibration procedure was adopted for these effects. For all 15 combinations of two loads, combined loads were applied. First, one load component was held constant at +75% of its load range and the other load component was varied from 0 to +75% and from 0 to -75% of its load range. Then the second load component was held constant at +75% of its load range and the first load component was varied from 0 to +75% and from 0 to -75% of its load range. After this procedure was finished for all the 15 combinations it was repeated but now the constant load was set to -75% of the load components range. Overall the 1st order calibration consisted of 280 data points and the 2nd order calibration consisted out off 717 data points. The calibration coefficients were obtained with a global regression analysis out of these 997 data points.

Since the BCM allows simultaneous application of 6 load components it was used to simulate a wind tunnel measurement of a typical DNW-LLF model.

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The simulated conditions represented a weight polar, a pitch polar, a yaw polar and a repeat of this yaw polar. This data in combination with the repeat of one single component 1st order calibration and the back calculated calibration points themselves were used to validate the calibration results and the calibration coefficients. As a final check the balance was also loaded to almost the maximum simultaneous loads, 90% of the FS load range on 5 components and 20% of the load range on the 6th component (M_z).
The complete 1st and 2nd order calibration of balance 664 and the checks, more than 1176 data points, were performed within a 3-week period (inclusive transport of the balance).

Finally, at the DNW-LLF, also the temperature effects of the balance were analyzed and calibrated. Although the balance has 'global' temperature compensation and calculations indicated only a small temperature effect, practice in the wind tunnel may prove different. The temperature effect in the wind tunnel stems from the temperature gradients over the balance, especially non-symmetric temperature distributions (e.g. when only one RALD tube is used). To investigate the temperature behavior a typical DNW-LLF model was mounted on the balance. The balance in turn was mounted to a dummy sting support system. To simulate a wind tunnel test a tent was build to cover the model and balance. The air in the tent was heated cyclically to represent wind-on and wind-off conditions. The dummy sting support system functioned as a heat sink similar to the real sting support system in the wind tunnel.

2.5 Results

First of all this large balance was delivered on time to DNW. The balance was designed, manufactured and calibrated with one year.

The calculated outputs of the balance are compared with the outputs during the calibration in the figures 6 and 7. For figure 6 the output of the bridge at all the six maximum load conditions is added up. Whilst in figure 7 the absolute maximum output of a bridge is presented. The latter figure indicates that the output of the bridge due to a single loading is predicted reasonably well with the FEM model. From figure 6 it can be concluded that there was an interaction on bridge R4 (rolling moment) that was not predicted fully. It appeared that a yawing moment causes more output on the rolling moment bridge than expected.

The accuracy coefficients for the new balance were derived from the results of the back calculated calibration data points, see table 2. The accuracy of the balance is better than that of balance W608. Also the results of the back calculated validation data points (out of the calibration) indicated a good performance of the balance. The maximum load point (90% FS load on 5 load components and 20% FS load on the M_z load component) resulted in the following errors. δ_{Fx} = 0.13%, δ_{Fy} = 0.17%, δ_{Fz} = 0.05%, δ_{Mx} = 0.04%, δ_{My} = 0.09%, δ_{Mz} = -0.04%. So it also can be stated that the errors are always smaller than 0.2% for each load component regardless of the load combination applied (this sets an extra upper limit to formula 2). The simulated wind tunnel polars are combined loads (at least 3 components) that are not part of the data set which was used to obtain the calibration coefficients. The errors in the back calculated loads are presented in the figures 8 through 10. These figures show a good performance of the balance. Figure 11 shows the results of the repeated simulated β polar. This figure shows that the repeatability is better than the accuracy for all load components except F_y for which it is more or less the same.

The theoretical deflections of balance W608 and B664 are given in table 3. The deflections were also measured for M_x and M_y during the calibration in the BCM. These results are presented in table 4. For comparison the deflection coefficients of W608 and W616 as measured in the BCM are also given in this table. Clearly the deflections coefficients of the balances W608 and B664 are of the same order of magnitude. Furthermore, the measured deflections coefficients have a similar tendency with respect to the theoretical values. It is also clear that balance W616 has greater deflections and is thus less suited for applications with air line bridges.

Figure 12 shows the increase in temperature (with respect to the start of each run) at the model and sting side of the balance. The data set comprises several runs over three days. The heating periods vary between ½ an hour and 3 hours whilst the long natural cooling periods vary between 4 to 6 hours. The global temperature gradient over the balance is presented in figure 13. The temperature gradient effect on R1 is shown in figure 14. Although the effect is within the accuracy range of the balance it was decided to correct for it. The used correction is based on a math model describing the deformations of the balance due to temperature gradients. The coefficients of the model were established utilizing the 18 temperature sensors in the balance and the balance output during the temperature test. The correction works satisfactory, see figure 14.

Finally the balance was put through a wind tunnel acceptance test (in 2003). The results were compared

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with test results with the same model and balance W608. This test dates back to 1992. The comparison in CL_{max} and CD_{min} is given the figures 15 and 16. The comparison in CD_{min} is excellent. The difference in CL_{max} may be explained by the fact that this comparison includes model and balance repeatability of a long period. The error bands in these plots are the single component accuracy for F_z and F_x of balance W608.
The repeatability with respect to a reference polar is presented in the figures 17 and 18. The repeatability is assumed to be 1/3 of accuracy coefficients of the new balance. Note further that the repeatability band is only based on single load component repeatability whilst at least 3 components are loaded simultaneously. The repeatability is good.

3 RALD 2001

3.1 Concept of RALD 2001

The parasitic forces introduced by air-supply line bridges combined with air-return line bridges is relatively high for conventional air line bridges, see figure 19. To improve this situation DNW has already developed an air-supply line bridge system with low parasitic force and moments (Ref. [4]). To complement these air line bridges an air-return line bridge system is developed. The air-supply line bridge system formed the starting point for the design of the air-return line bridges. The design is based on a so-called swan-neck air-supply line with three flexible pipe couplings. By using new materials it was possible to design and manufacture the flexible pipe couplings in such a way that they are symmetric, stable and have almost negligible hysteresis. Due to geometric constraints the flexible pipe couplings are positioned somewhat extraordinary: the return air enters the system vertically and leaves the system horizontally, implying a change in the momentum that the air line bridge system needs to overcome.

3.2 Concept verification

A first investigation was made into the behavior of the new air-return line system. Possible influences of the air-supply line system on the balance performance in terms of attainable accuracy were investigated. The investigation mainly focused on the overall functioning of the concept and the influence of the system on the axial load of the balance. The following aspects are to be distinguished:

- Change in the general characteristics of the balance on which the air-supply line system is mounted. Especially the change in sensitivity of the balance for certain loads, due to the additional stiffness introduced by the air-supply line system.
- Pressure effects. Pressurized air in the air-supply line system might result in parasitic forces and moments or even a change in the sensitivity of the balance.
- Temperature effects. Since the return air from the air motors will be cold the air-return line will be cold as well. The expected temperature in the air return line ranges from 10°C to -10°C. This will lead to a strain (dilatation) in the air-return line system, possibly resulting in parasitic forces and moments to the balance. Note that the air-supply line system, contrary to this, is heated!
- Momentum effects. The check on the primary goal of the air-supply and air-return line bridge, reduce parasitic forces and moments due to a momentum flow crossing the balance from non-metric to metric part.

These validations were done using balance W608 and the combined system of the air-supply line bridges (RALD 2000) and the air-return line bridges (RALD 2001).

3.3 Results

As already mentioned the validation mainly focused on the F_x component. The effect of the air-return line bridge combined with the air-supply line bridge on the sensitivity for the axial load of the balance to which it was mounted is small. The effect is large than the effect presented in reference [4] for only the air-supply line bridges (as is to be expected). The effect is 2 to 3 times as large which is nevertheless small. The effects are only just outside the balance accuracy range. The hysteresis introduced by both air line bridge systems is negligible.

Applying pressure to the air-return line bridges up to 16 Bar did not result in any significant deviations in the forces and moments, see figure 22.

The mass flow effect was established using a dedicated test set-up, see figure 21. Coupling of the air-supply line and the air-return line via an air motor simulator (a pipe with a choke plate in it) made it possible to check the momentum effects up to a mass flow of about 3.5 kg/s. The errors due to the momentum are presented in figure 23. Note that there are no corrections applied to the data. The effects are small and repeatable and thus correctable. An indication of the repeatability of the effects may be seen in figure 24. Here the mass flow effect on the axial component is presented for several repeat runs.

The temperature influences were finally check by cooling the tubes of the air-return line bridges. The results of this experiment are shown in figure 25.

Again the effect is very small. And for this effect no correction seems necessary.

4 CONCLUSIONS

The balance was developed manufactured and calibrated with one year.
The new balance B664 has met all the requirements set forth. Resulting in a balance with a performance equal to and for some components even better than, that of W608. This balance has already proven to be an asset. It allowed back to back testing of several model in the DNW-LLF in 2003 increasing the wind tunnel efficiency.

The first investigations on the effects of the air-return and air-supply line bridges on the performance of balance W608 indicate that the overall corrections for the parasitic forces and moments are small (same order of magnitude as the balance accuracy). The accuracy and repeatability of the balance will here for hardly be affected.

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Table 1: Load range

Load	W608/B664	W616
Fx	20000 [N]	6500 [N]
Fy	12500 [N]	10000 [N]
Fz	50000 [N]	20000 [N]
Mx	9000 [Nm]	4500 [Nm]
My	15000 [Nm]	7500 [Nm]
Mz	9000 [Nm]	3000 [Nm]

Table 2: Accuracy coefficients

Accuracy coefficients	Balance W608	Balance W616	Balance B664
a_{Fx}	1.5	1.2	0.6
a_{Fy}	1.7	1.1	1.0
a_{Fz}	1.3	1.0	0.5
a_{Mx}	1.5	1.4	1.0
a_{My}	1.0	1.2	0.6
a_{Mz}	1.0	1.4	0.5

Table 3: Theoretical balance deflections

Deflection coefficient	Balance B664 [°/Nm]	Balance W608 [°/Nm] (Requirement)
Mx	20 E-06	25 E-06
My	19 E-06	14 E-06
Mz	21 E-06	22 E-06

Table 4: Balance deflections in the BCM

Deflection coefficient	Balance B664 [°/Nm]	Balance W608 [°/Nm]	Balance W616 [°/Nm]
Mx	31 E-06	31 E-06	99 E-06
My	27 E-06	22 E-06	56 E-06

Table 5: Characteristics of RALD 2000 and RALD 2001

RALD	2000 supply	2001 Return
T_{max}	343 [K]	- [K]
T_{min}	275 [K]	263 [K]
P_{max}	80 [bar]	16 (12) [bar]
Massflow (two “tubes”)	12 [kg/s]	12 [kg/s]
Diameter	0.44 [m]	A400M model

FIGURES

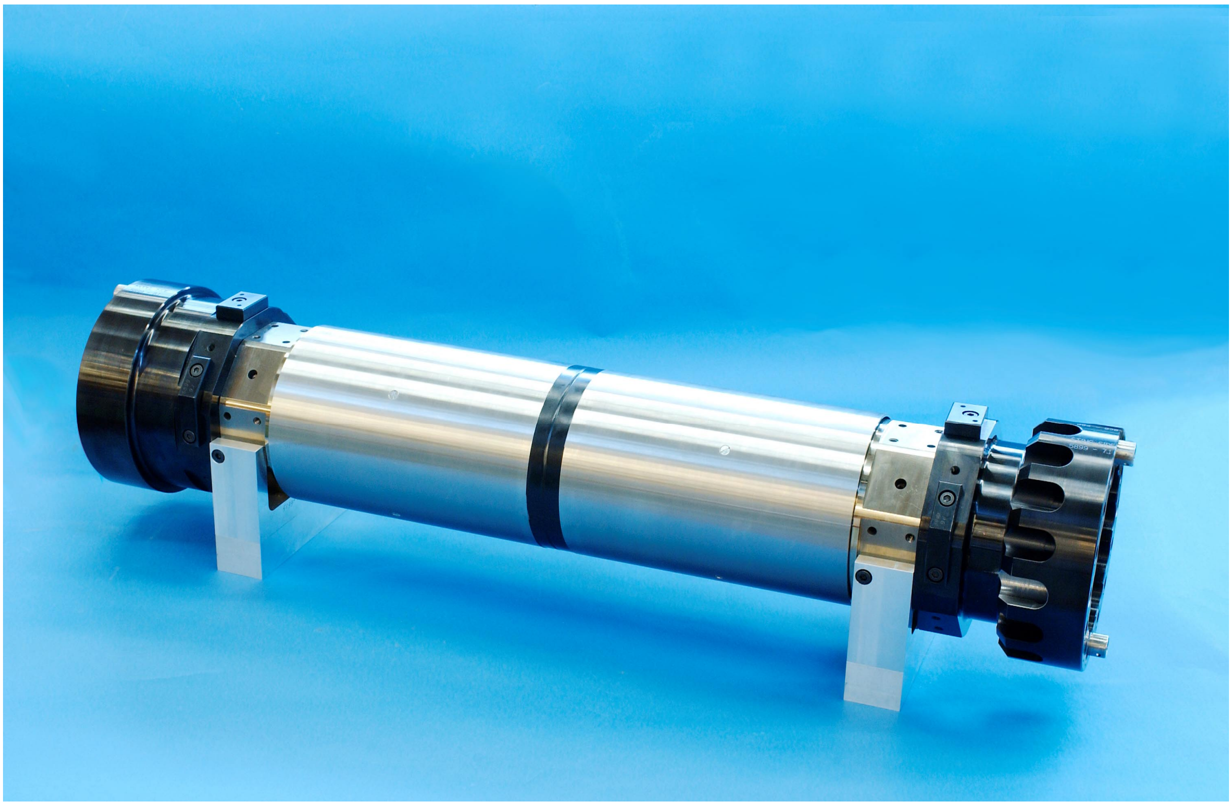

Fig.1 Balance 664 (inclusive adapters to W608 size)

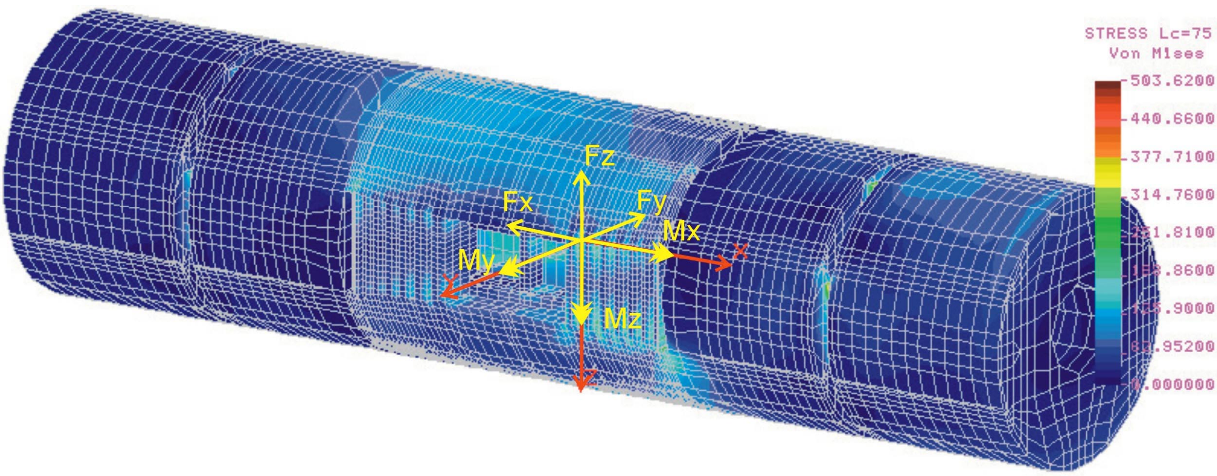

Fig.2 VonMises stress plot of the worst case load combination (Starboard view)

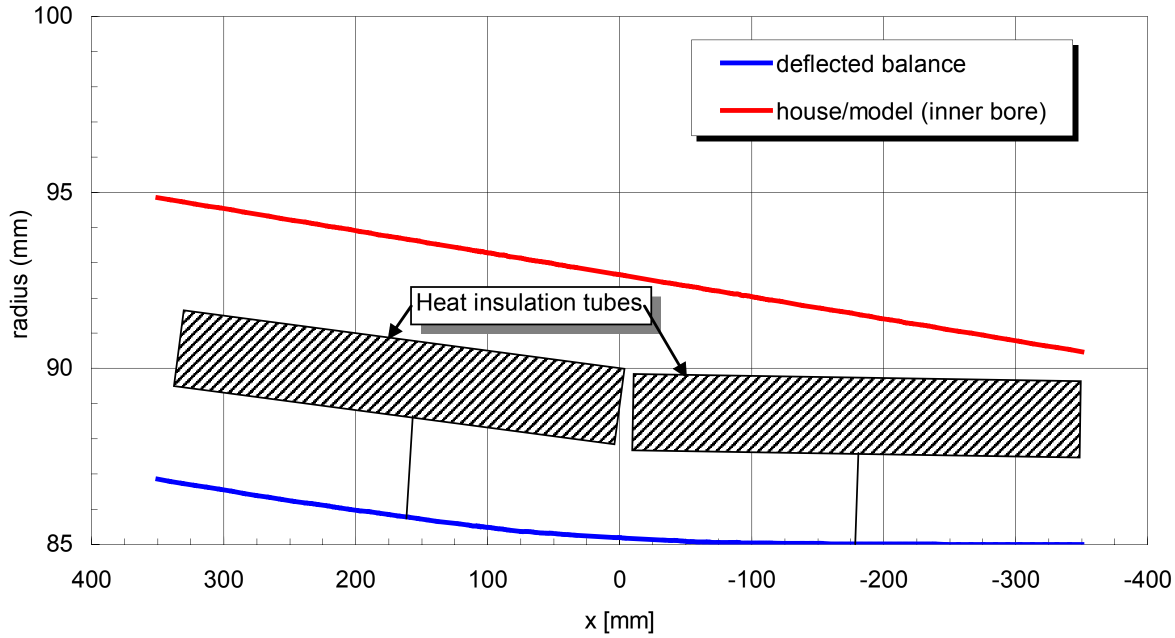

Fig.3 **Balance deformation (Finite Element Method,) outer side of the balance**

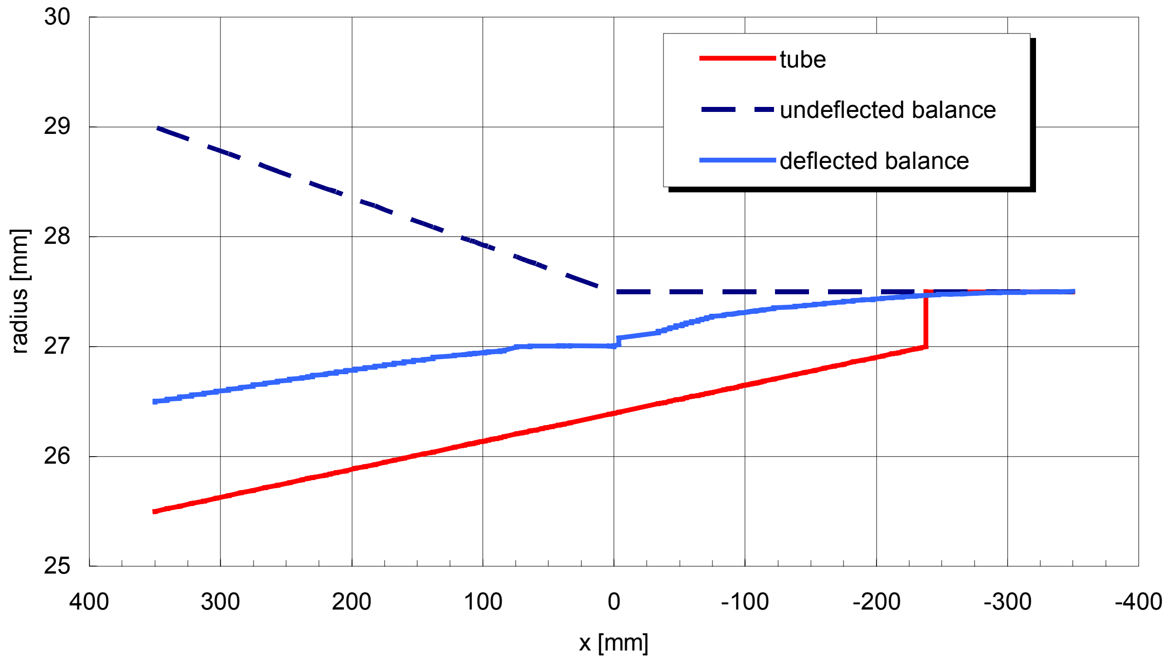

Fig.4 **Balance deformation (Finite Element Method,) inner side of the balance**

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Fig.5 ***Strain-gauge application on balance B664.***

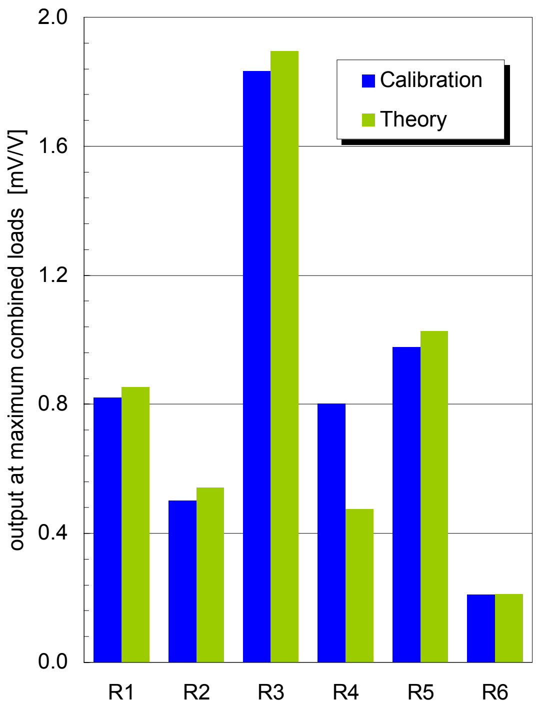

Fig. 6 ***Comparison between theoretical and measured output (total output)***

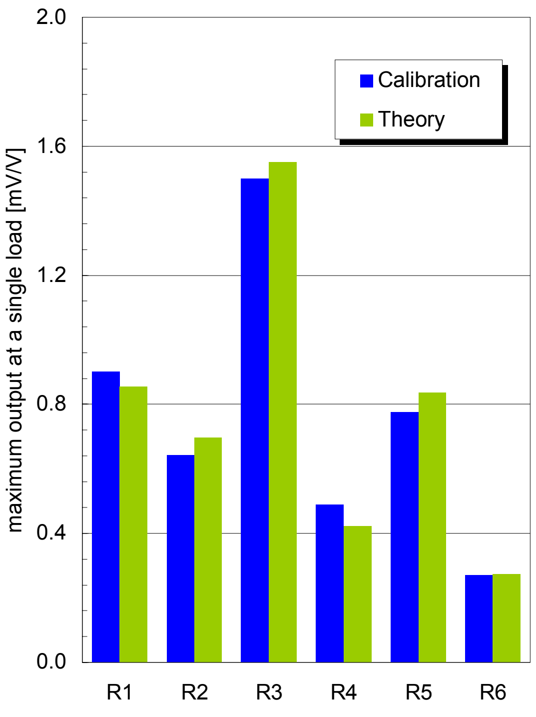

Fig. 7 ***Comparison between theoretical and measured output (max bridge output)***

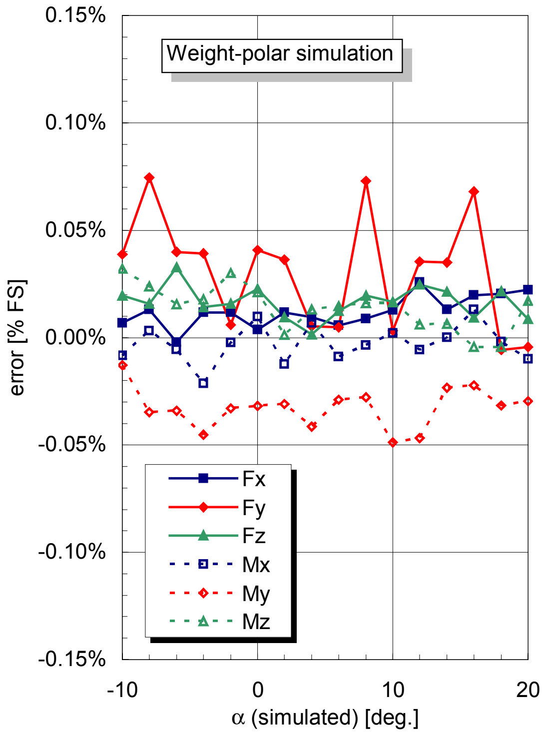

Fig. 8 ***Results of the BCM simulated weight polar.***

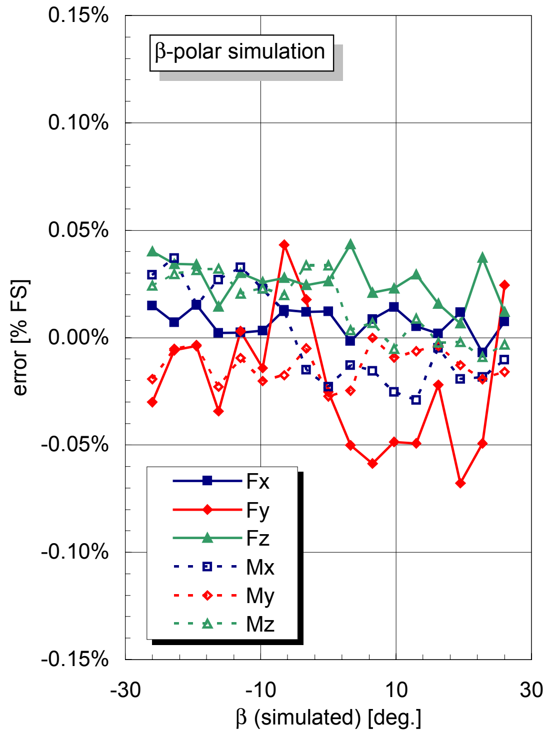

Fig. 10 ***Results of the BCM simulated β polar***

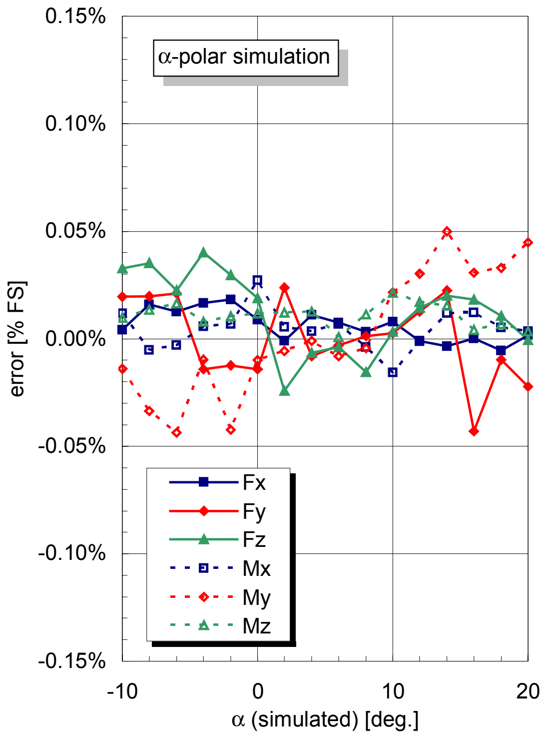

Fig. 9 ***Results of the BCM simulated α polar.***

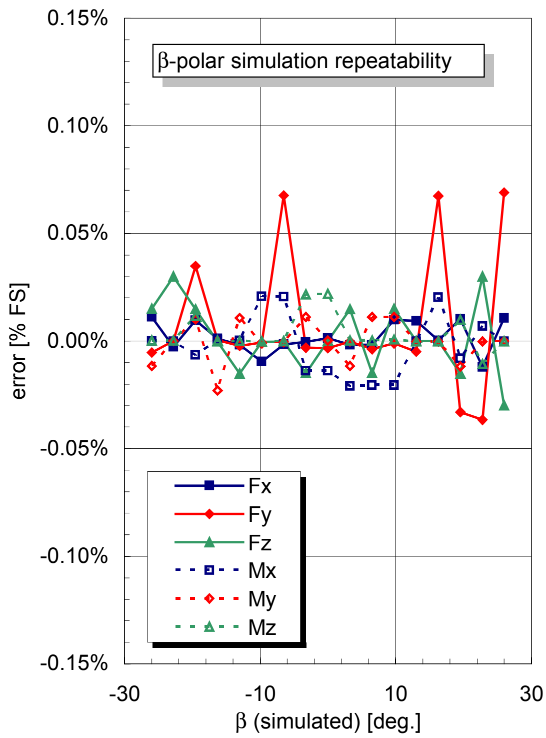

Fig. 11 ***difference in the error between two BCM simulated β polars***

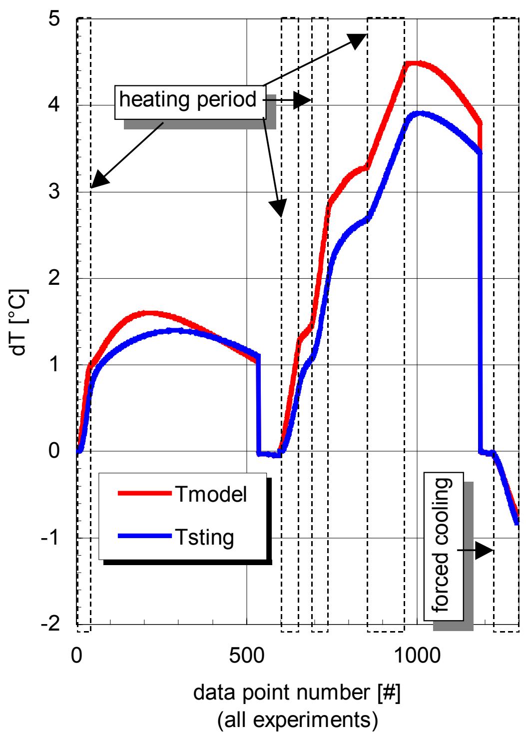

Fig.12 ***Balance temperatures during the temperature effect test***

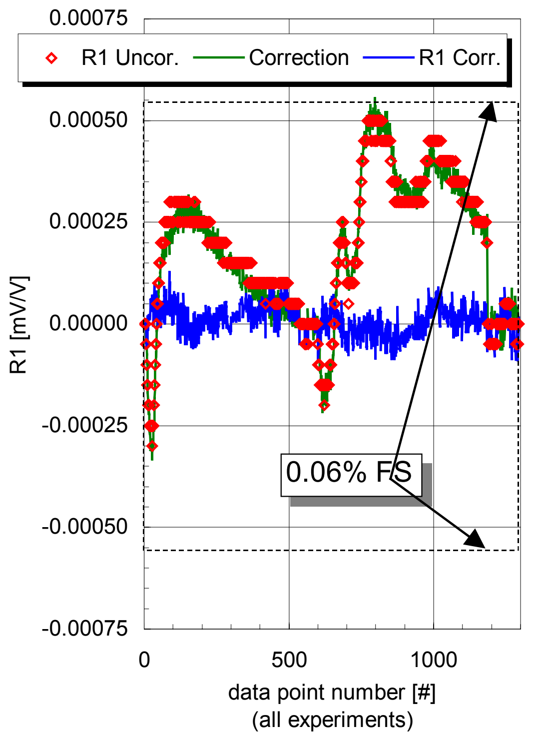

Fig.14 ***Temperature effect and correction for R1.***

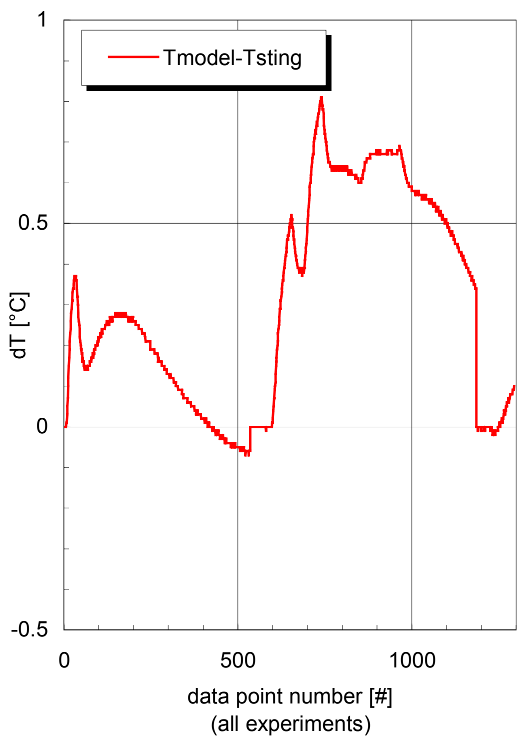

Fig.13 ***Temperature gradient over the balance during the temperature effect test.***

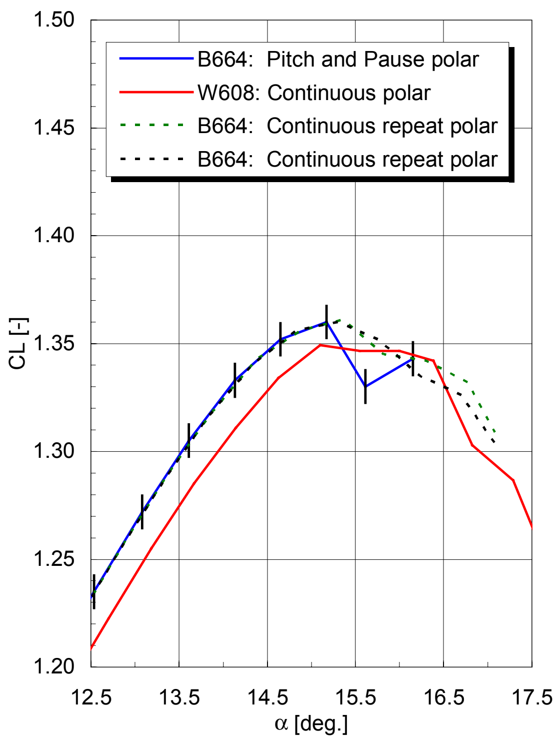

Fig.15 ***CL_{max} wind tunnel test comparison***

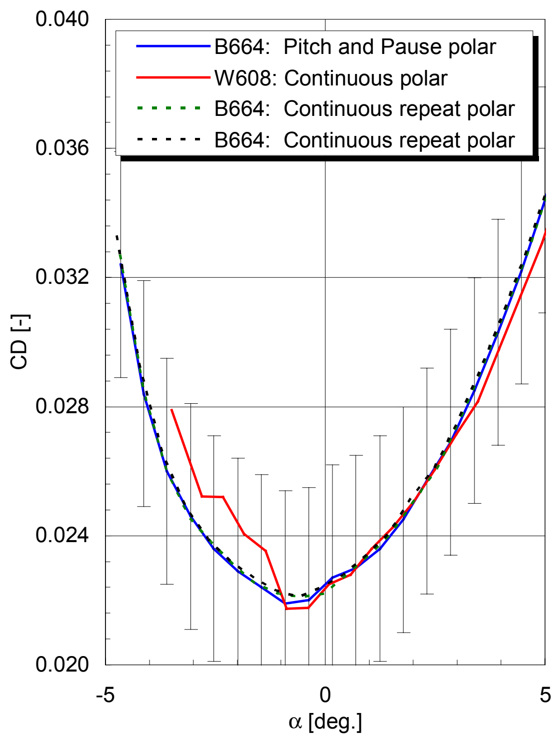

Fig.16 ***CD_{min} wind tunnel test comparison***

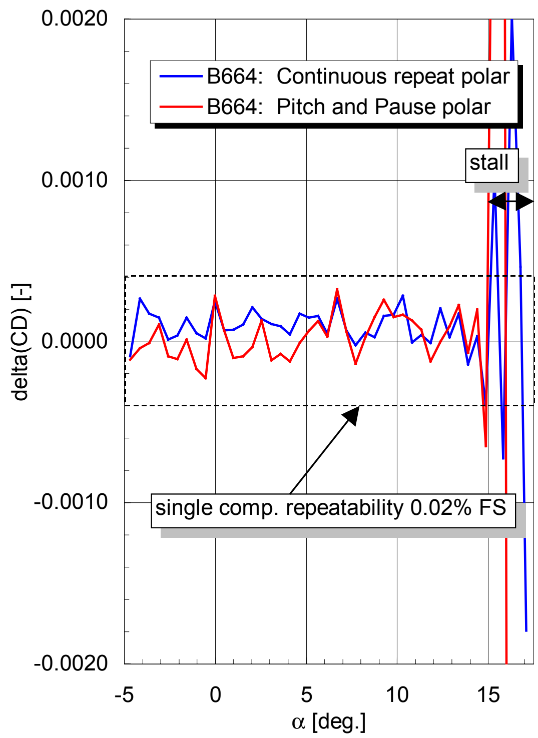

Fig.18 ***CD repeatability during wind tunnel test***

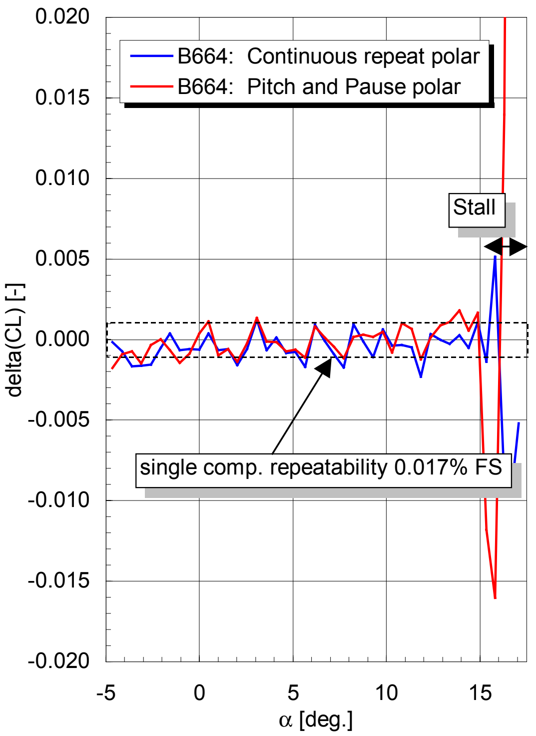

Fig.17 ***CL repeatability during wind tunnel test***

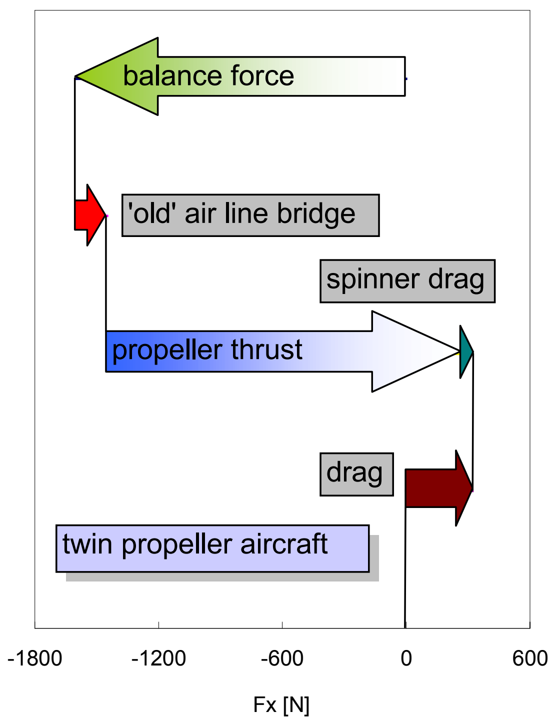

Fig.19 ***Thrust bookkeeping for propeller models***

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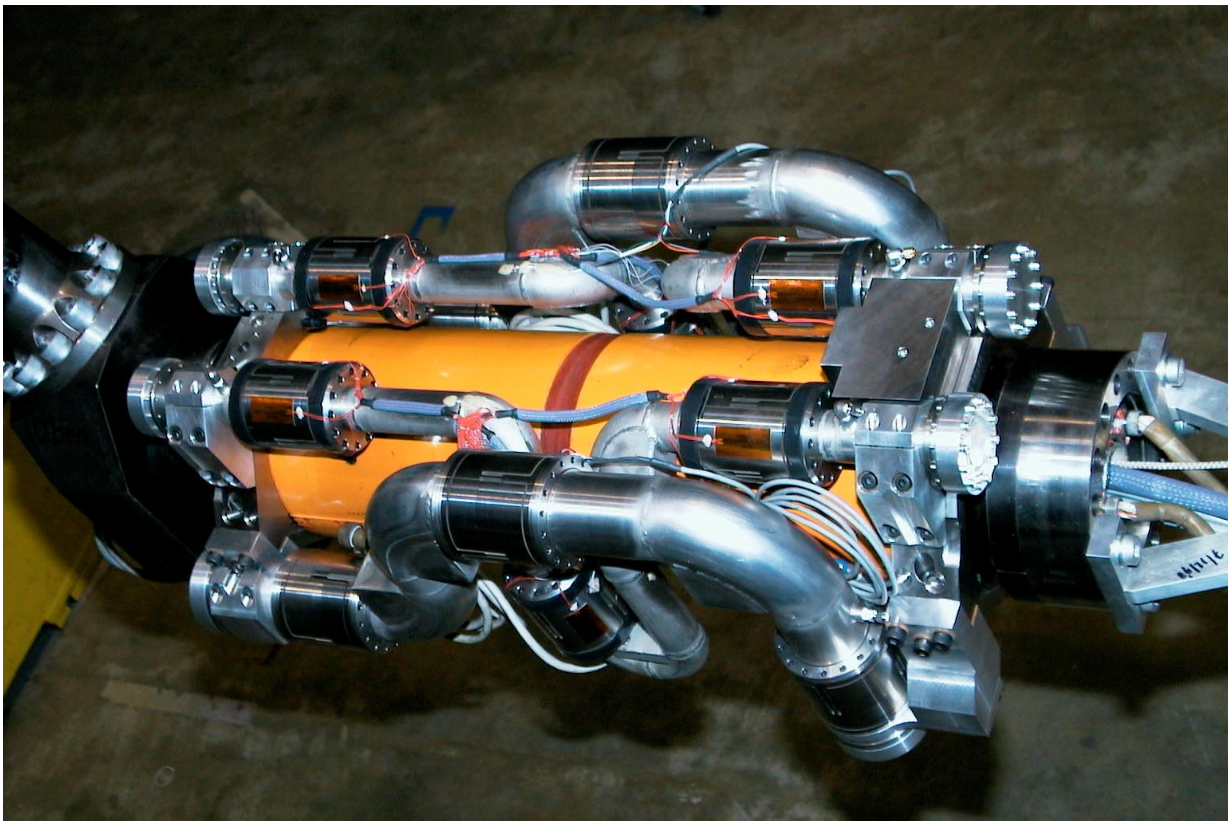

Fig.20 Balance W608 with air-supply and air return line bridges mounted.

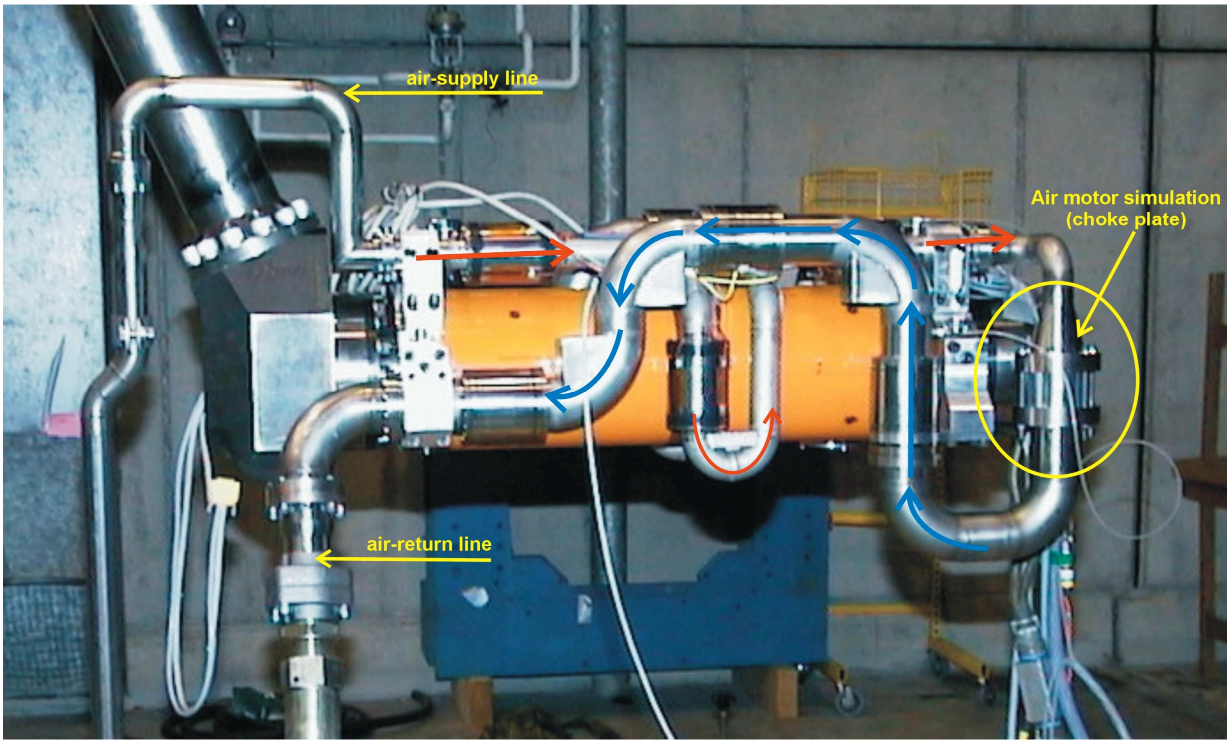

Fig.21 Test set-up for the mass flow effect test (air inclusive motor simulation).

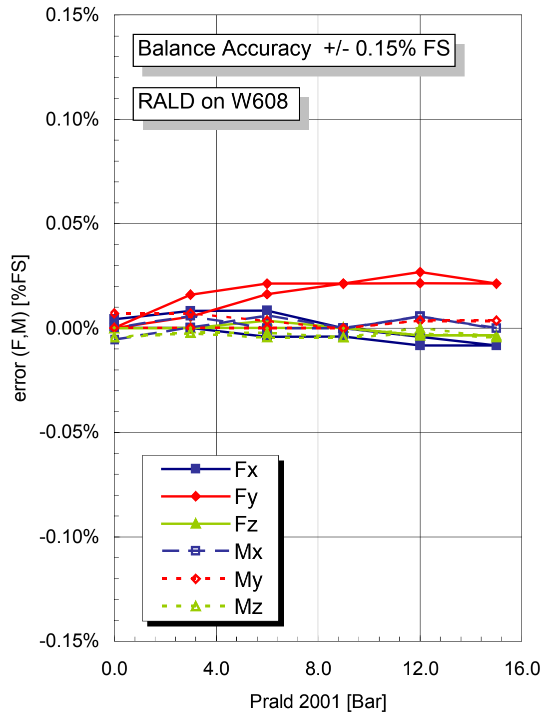

Fig.22 Pressure effect By RALD 2001

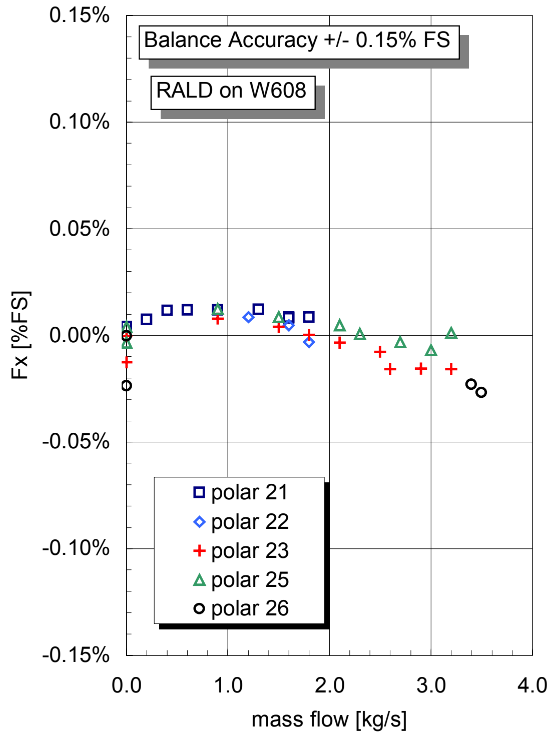

Fig.24 Mass flow effect (Fx) starboard side RALD 2000 and RALD 2001 (repeats).

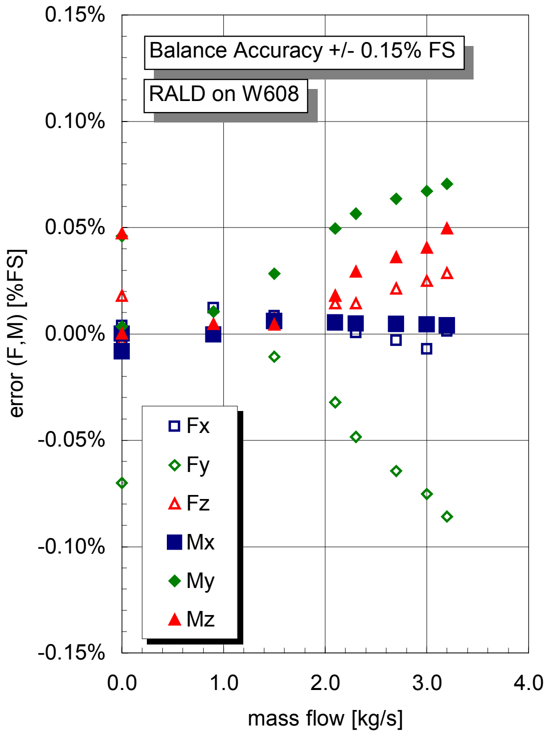

Fig.23 Mass flow effect starboard side RALD 2000 and RALD 2001

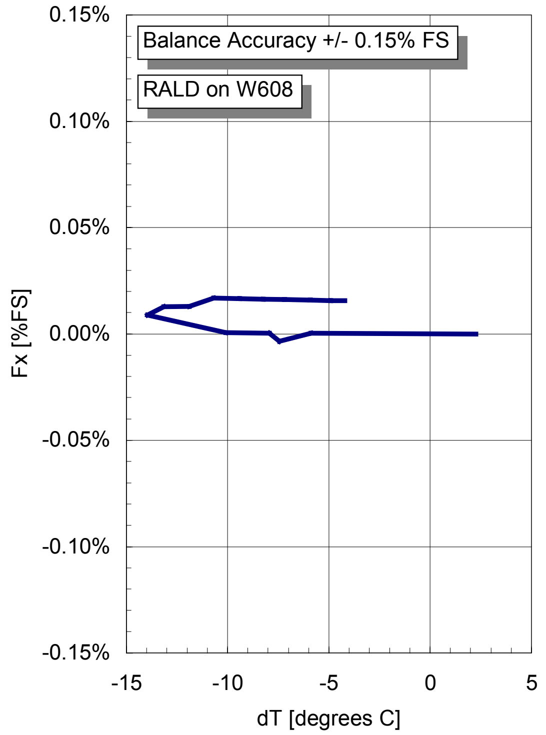

Fig.25 Temperature effect on starboard RALD 2001