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Wind tunnel measurement of small values of rolling moment using six-component strain gauge balance

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ABSTRACT

An experimental investigation was conducted to determine the accuracy of the rolling moment measurement in wind tunnel tests. The test was done in a high Reynolds number blowdown wind tunnel in subsonic, transonic and supersonic speed regimes. The rolling moment was measured on a missile model using an internal six-component monoblock strain gauge balance. The balance rolling moment element was designed as a five-bar cage measuring element. The expected rolling moment values in the test were significantly less than the balance rolling moment measuring element full scale. To check the accuracy of the balance measurement, a sensitive one-component transducer was designed and manufactured. In the first phase of the wind tunnel test, rolling moment was simultaneously measured using the balance and the sensitive transducer. Experimental data obtained using the balance was compared with those obtained by the transducer. It is shown that the balance data agree very well with the sensitive one-component transducer data.

1. Introduction

Wind tunnel balances are a complex, elastic structure designed to measure aerodynamic load which is generated on a model during experiment. Wind tunnel balances can be classified according to the number of aerodynamic load components which can be simultaneously measured and also according to the location where they are placed. If the balances are placed inside the model they are referred to as internal balances [1]. If they are located outside the model or the wind tunnel test section, they are referred to as external balances [2–4]. The balances can be also divided into mechanical balances, strain gauge balances, piezoelectric balances and magnetic suspension balances according to the measurement principle [5–8]. At present, strain gauge balances are the most widely employed for force and moment measurements in wind tunnels [9–11]. A monoblock six-component internal strain gauge balance in a wind tunnel model and components of the aerodynamic load are shown in Fig. 1, where R_X, R_Y and R_Z are axial, side and normal forces, M_L, M_M and M_N are rolling, pitching and yawing moments. In principle, the strain gauge balance is a model supporting structure so designed that the strains in particular sections are primarily proportional to one of the load components acting on the model. By bonding resistance strain gauges to the measuring sections and connecting them to form measuring bridges, electrical output signals which are proportional to the various forces and moments can be obtained. The strain sensors usually are resistance foil strain gauges, however semiconductor gauges are also used [12].

Many forms of strain gauge balance exist and each of them is appropriate to a particular set of circumstances. It is rarely, if ever, possible that an internal balance designed for one model will also be ideal in all respects for a different models. Thus, the equipment in a wind tunnel test facility includes a collection of strain gauge balances of different sizes as well as varying capabilities and characteristics. This collection is built up over a period of time and each of balances is designed and made when it is found that the collection up to that time does not include an appropriate balance to the test in question however, designing and manufacturing of a new balance always takes a long period of time, consequently testing a new wind tunnel model often necessitates selection of the appropriate balance among the already existing balances in the wind tunnel test facility. Selection of the appropriate balance is based on very contrasting requirements. This is particularly so in the blowdown pressurized wind tunnels where balances have to be chosen to withstand huge loads at the start and at the end of the wind tunnel runs. Also, these balances have to enable measurements of the multiple different magnitudes of aerodynamic loads which are generated on the model in the wind tunnel test section [13].

One of the most challenging aerodynamic components in wind tunnel measurements is rolling moment component. The ratio between full scale (FS) of the rolling moment component and FS of the other

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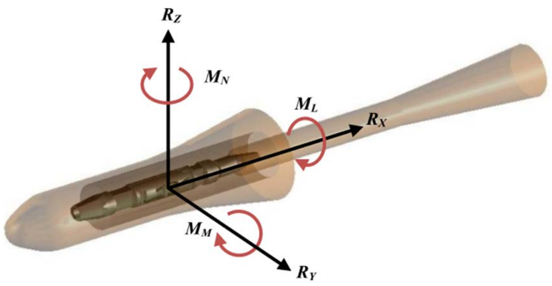

Fig. 1. Components of the aerodynamic load.

balance components can reduce the accuracy in rolling moment measurements [14]. In wind tunnel tests, rolling moment values can be multiple times smaller than the values of the other components. These are reasons why great attention is paid to the design of the rolling moment measuring element on the internal strain gauge balances.

Usually internal multi-component strain gauge balances have forward, backward and central measuring sections. In most cases, rolling moment measuring element is realized on the forward measuring section, which can contain one or a several measuring bars. The simplest way to measure rolling moment is to use an element with massive rectangular geometry as a measuring section with one bar [15]. In this case the balance forward and backward measuring sections is shaped as a single central bar. The strain gauges axes are inclined at 45° to the balance longitudinal axis as it is shown in Fig. 2. The gauges are connected in the way to obtain a four arm measuring bridge. The disadvantage of such measuring configuration appears when some adjustments are made to the dimensions of the bar to control the level of stress and hence the strength of the output signals. Such adjustments may have an effect on the performance of the balance components and make the output signal from a rolling moment bridge undesirably small.

A rolling moment measuring element shaped as a four bar cage is shown in Fig. 3. Such element was used as a rolling moment measuring element on an internal six-component balance, which was used to determine the hydrodynamic load at a model test conducted in a water tunnel [16]. The measurement is obtained through a cross shaped section made up of four rectangular bars where four strain gauges are accurately installed on each of the four bars at the end of the section. The strain gauges are connected to form one measuring bridge: a half bridge on the two horizontal bars and the other half on the two vertical bars. For this cross-shaped section, the deformation created by the rolling moment is directly converted to pure bending in the bars. This design of the measuring element enables measurement of very sensitive rolling moment changes; however such configuration can't ensure a sufficient stiffness for relatively high loads.

Measurement of the rolling moment using the central measuring section shaped as a five bar cage, Fig. 4, is described in [17,18]. The problem of occurrence of small amplitudes of output signals from forces and moments sensors is common in wind tunnel measurements of dynamic stability derivatives [19]. The use of five-component semiconductor strain gauge balance in wind tunnel dynamic tests has significantly improved the accuracy of the measurements. In the most of the dynamic experiments presented in [17,18], the roll-damping derivative measurements showed very good results even though the amplitude of the excitation moment signal in roll is less than 2% of the balance rolling moment element FS.

This paper, presents a set of experiments done in the T-38 wind tunnel of the Military Technical Institute in Belgrade (VTI) [20]. Aerodynamic load on a missile model was measured in Mach number range from 0.5 to 2.0. During the preparation of the wind tunnel test, estimation of the aerodynamic load on the model showed that expected values of the rolling moment were very small. Basing on the analysis, which concerns the rolling moment measurement (expected values of the rolling moment were below 2% of the balance rolling moment FS), an internal six- component balance, whose rolling moment element is shaped as a five bar cage, was chosen to be used during the tests. In order to verify the accuracy of the balance measurement, a sensitive one-component transducer was designed and manufactured to measure a nominal value of rolling moment equals to 0.6 Nm. For that aim, a phase of tests, in which the rolling moment was simultaneously measured with the sensitive transducer and the balance, was done. At this phase, both of the balance and the transducer were mounted together inside the missile model. Another test phase was done using only the balance to measure aerodynamic loads at the missile model.

2. Experimental setup

The T-38 wind tunnel of the VTI is a blowdown-type pressurized wind tunnel, Fig. 5. Mach number in the range 0.2–4.0 can be achieved in the test section. The $1.5 \times 1.5\,\mathrm{m}^2$ square test section with solid walls is used for subsonic and supersonic tests, however for transonic tests, a $1.5 \times 1.5\,\mathrm{m}^2$ square section with porous walls and blow off system is inserted in the wind tunnel configuration to achieve transonic Mach numbers. The porosity of walls can be varied between 1.5% and 8% depending on the value of Mach number in the wind tunnel run. Stagnation pressure can be between 1.1 and 15 bar depending on the desired value of Mach number and it can be regulated to 0.3% of its nominal value. The Mach number during the test is regulated within 0.5% of the nominal values. Depending on Mach number and stagnation pressure, run times can be from 6 s to 60 s. One of the main advantages of the T-38 wind tunnel is its high-Reynolds number capability: up to 110 million per meter.

During the presented tests, the Mach number range was from 0.5 to 2. Depending on the speed range in the test section adjustment of Mach number was defined as following:

- In the subsonic configuration Mach number was set by sidewall flaps in the tunnel diffuser.
- In the supersonic configuration Mach number was set by the flexible nozzle contour.
- In the transonic configuration Mach number was set by sidewall flaps and flexible nozzle and it is actively regulated by a blow-off system.

The Mach number, M, and dynamic pressure, q, in the test section

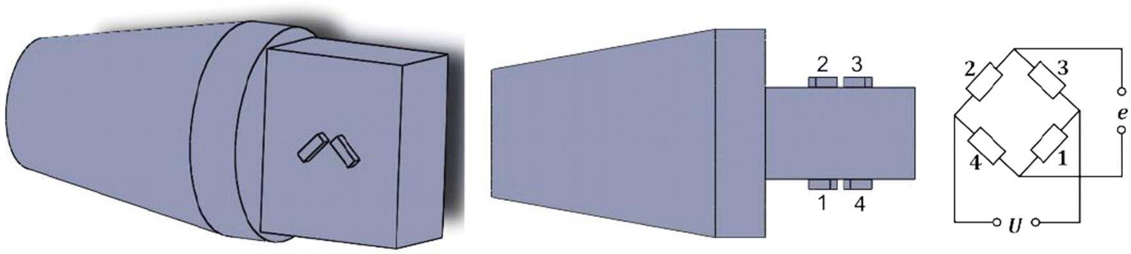

Fig. 2. Measuring element with one bar.