DEVELOPED COMPUTER AIDED INSPECTION METHOD FOR FREE-FORM SURFACES APPLIED ON AERONAUTICAL LIFT AND CONTROL SURFACES

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Abstract:

Angular relationships of lift and control surfaces, wings and all the elements needed to determine the model for wind tunnel testing are essential to the quality of the final assembly. In relation to the measurement of airfoil shape deviation from this determination is complicated and requires complex mathematical models and calculation. It is necessary to find the plane that represents the wing and calculate the required angular relationships such as the wing setting angle and the dihedral angle. Such a plane exists on the wing and is called the Wing Reference Plane (WRP). This plane is not material and its direct measurement is impossible.

Identifying dihendral angle, wing seting angle and local airfoil twisting of models aircraft is accomplished by measuring the WRP. Detection of these parameters are required to model the quality of the final geometric inspection. The developed method requires the preparation of measurement and calculation of the CAD/CAM system. It takes information about the relationship between WRP and the upper and lower wing surface transferred to the coordinate inspection program. Over the measured coordinates apply a special system of equations. The result of the calculation is measured WRP. The developed method can also be successfully applied to measure the deflection angle of canards, slats and flaps.

Wing of wind tunnel model LASTA-2 (Swallow P2), is taken as an example of application of the developed computer aided inspection method.

Keywords: Intelligent Measurement, Angular Relationships in Space, Aeronautical Surfaces

1. INTRODUCTION

Design and development of aircraft is a long and complicated multidisciplinary process. Support the development and design of the aircraft is wind tunnel testing, used for the verification of theoretical calculations. The aircraft wind tunnel model does not fly, but is attached to the carrier of model. In order to simulate flying conditions it is necessary to speed and dynamic pressure of air flow around fixed model as closely as possible reflect the real flight conditions. The assumption of similarity is the starting point for all tests of experimental aerodynamics [1]. The first and one of the most important requirements is the geometric similarity. External geometry of the model aircraft or missile is almost always described using free-form surfaces; geometric similarity model checking can be performed only using specialise developed method of coordinate metrology.

Key elements of the model and the most responsible are the lift and control surfaces: wings, fins, flaps, slats, vertical and horizontal tail. These elements are described by free-form surfaces, and the increased demands of accuracy in relation to the other elements of the model. Models of aircraft after manufacturing become an integral part of the aerodynamic laboratory (wind tunnel).

Inspection of the geometry element model for wind tunnel testing of aircraft carries many characteristics in relation to other classes of objects described free-form surfaces. It is primarily caused by the shape, configuration and design solutions. Besides the shape, main interest is their relationships in a space.

2. AIRFOIL & WING GEOMETRIC DEFINITIONS

2.1 Airfoil terminology

The shape of a wing or blade (of a propeller, rotor, or turbine) or sail as seen in cross section is called airfoil (aerofoil). Body shaped by airfoils cause's aerodynamic forces: lift and drag. The lift on an airfoil is primarily the result of its angle of attack and shape.
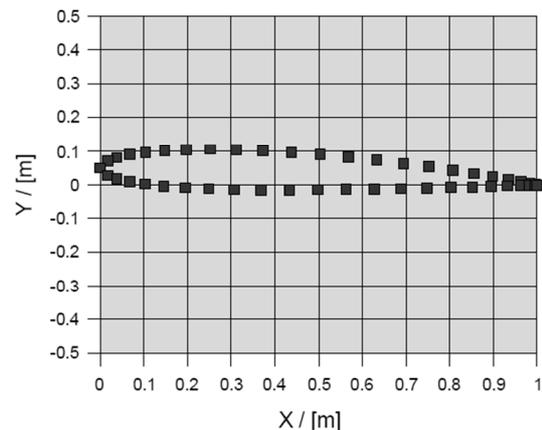

Fig. 1. NACA 5012 - aerofoil definition points

Airfoils are described in tables and classified using 4 and 5 digits. Upper and lower side of the airfoil is defined by the control points for the range of 0 to 100% (Fig.1.).
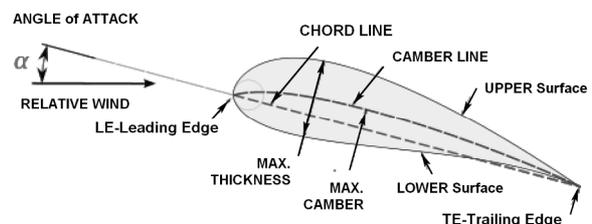

Fig. 2. Airfoil nomenclature

The various terms related to airfoils (Fig.2.) [2]:

Upper surface is generally associated with higher velocity and lower static pressure.

Lower surface has a comparatively higher static pressure than the suction surface. The pressure gradient betwee these

two surfaces contributes to the lift force generated for a given airfoil.

The Leading Edge (LE) is the point at the front of the airfoil that has maximum curvature.

The Trailing Edge (TE) is at the rear of the airfoil.

The chord line is a straight line connecting the LE and TE of the airfoil.

The chord length (or just chord) is the length of the chord line and is the characteristic dimension of the airfoil section.

The mean camber line is the locus of points midway between the Upper and Lower Surfaces.

The thickness of an airfoil varies along the chord. It may be measured in either of perpendicular to the camber line or measured perpendicular to the chord.

The aerodynamic center, which is the chordwise length about which the pitching moment is independent of the lift coefficient and the angle of attack.

The center of pressure, which is the chordwise location about which the pitching moment is zero.

2.1 Wing positions in space

The shape of the wing, when viewed from above looking down onto the wing, is called a planform. For a rectangular wing, the chord length at every location along the span is the same. For most other planforms, the chord length varies along the span.

Fig. 4. Geometric and Aerodynamics Aerofoil Twisting

Individual airfoils are in the plane perpendicular to the WRP scaled chord to the fixed length. If any of the airfoil is rotated then it is called geometric twisting of airfoil. If you change the airfoil along the span it is called aerodynamic twisting (Fig. 3.) [3].

Transformation matrix exactly defines the position of the wings in a airplane (absolute) coordinate system. Components of the normal vector of the wing reference plane give us information about setting and dihedral angle.

Table 1. Wing transformation matrix

	X- axis	Y- axis	Z- axis
Translation	2825	0	-520
Norm. I	0,999391	0,001826	0,034899
Norm. J	0,000000	0,998630	-0,052336
Norm. K	-0,034899	0,052304	0,998021

A typical example of a transformation matrix is given in Table 1. The data in the table refer to the aircraft wing Swallow which is designed in Military Technical Institute (MTI) Belgrade. Component **I** of the normal vector along the X axis gives the value of the wing setting angle (ACos0,999391=2°) Component **J** of the normal vector along the Y axis gives the value of the wing dihedral angle

(ACos0,998630=3°). Figure 4. shows the wing set in space according to the data in Table 1.

Aerodynamic calculations made by principal project request data provide the basis of floating characteristic of lift and control surfaces of airplane. For example, wing of Lasta-2 (Swallow) airplane have following data:

- Trapezoid plan form
- Area: 12.9 m^2
- Span: 9015 mm
- Airfoil NACA 63_2-415 along the span
- Root Chord: 1789 mm, not twisted
- Tip Chord: 1073mm, twisted 3°
- Sweep angle: 0° at 30% of Chord line
- Wing Setting angle +2°
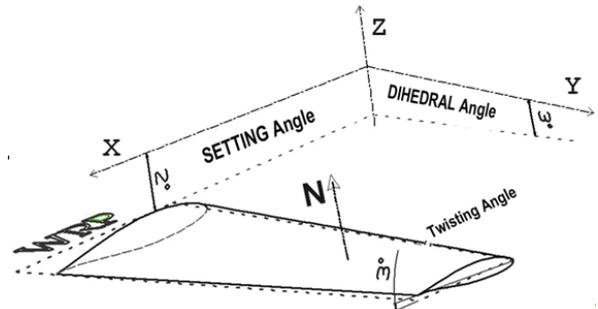- Wing Dihedral angle 3°

Fig. 3. Lasta- 2; Wing position in space - LASTA

Checking and correcting the theoretical aerodynamic calculations performed by experimental methods in wind tunnels.

3. WIND TUNNEL MODELS TOLERANCES

Geometric similarity is the primary requirement that is placed in the project application for model manufacturing. The wind tunnel tests are laboratory tests and the requirements for the accuracy of the model is very high. The model is reduced compared to the aircraft but the tolerances are obtained by simple scaling of tolerances that apply to aircraft that are produced in a factory. Tolerance models are much narrower. Inverse is also true: the geometry tolerances of the aircraft are not simply the product of the external geometry of the model tolerance. They are much wider. When it comes to similarity geometric model for wind tunnel testing and the original geometry of the aircraft are different aerodynamic and technical tolerances.

Aerodynamic tolerances are related only to the aerodynamic performance of the aircraft model.

Technical tolerances provide functionality and validity of all connections in the model and the actual carrier (sting).

Comparisons manufacturing tolerances of models for wind tunnel testing at the MTI and the world's leading laboratories (TsAGI, ARA, NLR, Deharde, ONERA, NASA) indicate closeness of these values.

For example, tolerance of wind tunnel model LASTA-2 (Scale1:5) for large subsonic wind tunnel T-35 [3] are listed below [4]:

- Fuselage ± 0.10 mm

- Overall lenght ± 0.25 mm
- Wing Chord ± 0.10 mm
- Wing Span ± 0.20 mm
- Wing Setting Angle ± 0.10 °
- Wing Dihedral Angle ± 0.10 °
- Airfoil thicknes ± 0.10 mm
- Airfoil shape ± 0.05 mm
- WRP position ± 0.20 mm
- Tail-WRP relation ± 0.10 °
- Tip chord twisting ± 0.05 °

3. WRP MEASURING METHOD

The developed method requires the preparation of measurement and calculation of the CAD/CAM system. It takes information about the relationship between WRP and the upper and lower wing surface transferred to the coordinate inspection program.
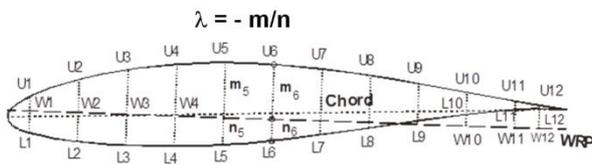

$$\lambda = -\ m/n$$

Fig. 5. Points on the upper and lower side for WRP

Figure 5 shows the generated points on the upper and lower surface of the airfoil (wing) and to determine the shortest distance to the WRP. Thus obtained the distance to the WRP used to calculate the parameters of dividing for every pair of points on the upper and lower surface of the wing.

Dividing parameter λ is passed to the program coordinate inspections with the theoretical coordinates of the points where the measurement takes place. For the coordinate measuring machines with three dimensional touch trigger probe (3D-TTP) it is necessary to pass theoretical (obtained from CAD file) coordinate for each measuring points and components of probe approaching vector [6].
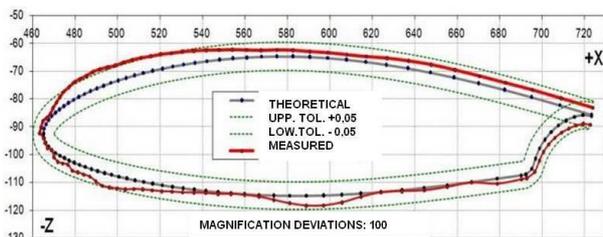

Fig. 6. Deviation Diagram: Measured - Theoretical Airfoil

Figure 6. represent typical type of deviation diagram of measured airfoil. Deviations measured / theoretical were magnified 100 times to make it easier to pick fault in manufacturing process. Diagram also shows upper and lower tolerance limit.

To obtain a position in space, especially the wing setting angle and dihedral angle, it is necessary to apply the following system (1) of equations:

$$X_{MW} = \frac{X_{MU} - \lambda_i \cdot X_{ML}}{1 - \lambda_i}$$

$$Y_{MW} = \frac{Y_{MU} - \lambda_i \cdot Y_{ML}}{1 - \lambda_i} \qquad (1)$$

$$Z_{MW} = \frac{Z_{MU} - \lambda_i \cdot Z_{ML}}{1 - \lambda_i}$$

Where $[X_{MW}, Y_{MW}, Z_{MW}]$ represent measured coordinate of WRP, $[X_{MU}, Y_{MU}, Z_{MU}]$ represent measured coordinate of upper side of airfoil, $[X_{ML}, Y_{ML}, Z_{ML}]$ represent measured coordinate of lower side of airfoil, and parameter λi represent distance between upper and lower theoretical airfoil points and WRP on wing part file on CAD/CAM system.

For symmetric and non-twisted airfoil dividing parameter always $\lambda = -1$. Calculation of WRP measured points is simplified because the measured points are arithmetic mean (middle points). This is mostly the case with missiles and rockets. Vertical tail of airplane always is defined with symmetric airfoil. In this case applies to the following system (2) of equations:

$$X_{MW} = \frac{X_{MU} + X_{ML}}{2}$$

$$Y_{MW} = \frac{Y_{MU} + Y_{ML}}{2} \qquad (2)$$

$$Z_{MW} = \frac{Z_{MU} + Z_{ML}}{2}$$

Thus obtained measured coordinates are used to calculate the WRP using dual linear regression equation. The coefficients of the general form of the equation of plane (3) are obtained from following system (4) of equations:

$$z = A + B \cdot x + C \cdot y \qquad (3)$$

Where A, B, C are coefficients of regression calculate by equations (4):

$$\sum_{i=1}^{n} Z_{iMW} = A \cdot n + B \cdot \sum_{i=1}^{n} X_{iMW} + C \cdot \sum_{i=1}^{n} Y_{iMW} \qquad (4)$$

$$\sum_{i=1}^{n} X_{iMW} \cdot Z_{iMW} = A \cdot \sum_{i=1}^{n} X_{iMW} + B \cdot \sum_{i=1}^{n} X_{iMW}^{2} + C \cdot \sum_{i=1}^{n} X_{iMW} \cdot Y_{iMW}$$

$$\sum_{i=1}^{n} Y_{iMW} \cdot Z_{iMW} = A \cdot \sum_{i=1}^{n} Y_{iMW} + B \cdot \sum_{i=1}^{n} X_{iMW} \cdot Y_{iMW} + C \cdot \sum_{i=1}^{n} Y_{iMW}^{2}$$

Transformation equations of the plane in normal form (3) in the canonical form (5) we obtain the required angle cosines of wing setting angle and dihedral angle.

$$I \cdot x + J \cdot y + K \cdot z + D = 0 \qquad (5)$$

Where I, J, K are components of plane normal vector and D is minimum distance from coordinate system origin.

The method developed and applied a mathematical model can be successfully applied to measure the deflection angles

of control surfaces by measuring their reference plane / chord plane.

4. PRACTICAL APPLICATION OF THE DEVELOPED METHOD

The developed method is successfully applied in the design department for design and production of model for wind tunnel testing in MTI Belgrade. Presents methods to determine deviations from the shape and position deviation in space are crucial for quality control of production models for wind tunnel testing. These methods are applied after each machining operations as well as for the final identification of the quality parameters of the model.
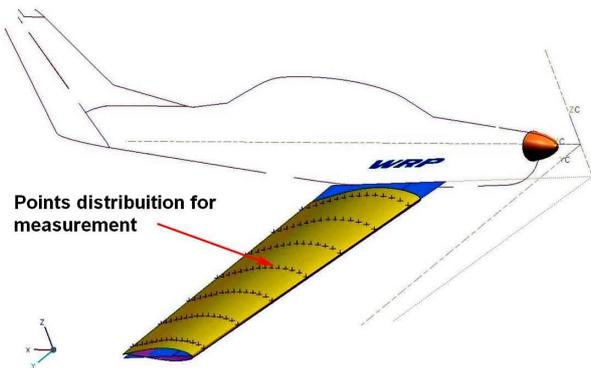

Fig. 7. Preparing the WRP measurement on CAD/CAM

The first step is the preparation: the generation and distribution of points on the upper and lower surface of the wing. This step is executed on CAD/CAM system. For each pair of points on the upper and lower wing surface is dividing parameter λ calculated as already explained. Theoretical coordinates of the generated points and the normal vectors of the local surface of the wing are transferred to coordinate inspection program.

The second step is the execution of coordinate measuring machine. CMM collects measured coordinates the entire set of previously generated points. Deviations from the form of individual wing sections are given as a diagram in Fig. 6.
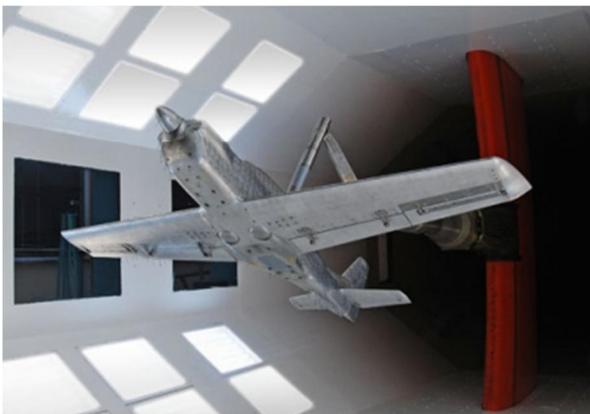

Fig. 8. Model of airplane LASTA (scaled 1:5) in large subsonic wind tunnel T-35

Deviation of position in space, described by wing setting angle and dihedral angle, are calculated over the entire set of measured points of the upper and lower surface of the wing using the equations (1-5).

For example, model for wind tunnel testing of airplane LASTA (Fig. 8.) was measured wing setting angle of 1.9973° and a dihedral angle of 3.0057°. These values are very close to theoretical and within a defined tolerance field.

5. CONCLUSIONS

The present article is part of a larger study [4] whose primary objective was quality management of manufacturing process of aircraft models for wind tunnel testing. Models for wind tunnel testing and are unique in their design and production takes months of work. Models of aircraft are defined by the free-form surfaces and have high demands for geometric accuracy.

The presented method is developed because commercial software packages for coordinate metrology are not able to fully meet the requirements of the production process and the final measurement wind tunnel models geometry.

All developed and presented method successfully applied on several different forging and domestic project.

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