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ADVANCED METHOD OF WING REFERENCE PLANE MEASURING

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Abstract – Determination of angular relationships of aircraft lift and control surfaces (wings, flaps, ailerons, tail, rudder and canard) are essential to the quality of the final assembly. The identification of dihedral angle, wing setting angle and deflection angle is accomplished by measuring the Wing Reference Plane (WRP). Paper presents advanced mathematical and metrological fundamentals for measuring WRP. The presented method allows the deviation of form and position deviation considered separately for aeronautical surfaces. Developed method successfully applied on several international and domestic projects.

Keywords: Measurement, Geometry, Aeronautical Surfaces, Wing Reference Plane

1. INTRODUCTION

The reasons for the implementation of freeform surfaces in industry are functional and aesthetic [1]: automotive and aerospace industries, household appliances and others. Turbine blades and aircraft wings are defined using very different airfoils. In some cases, requested a very high accuracy of the aerodynamic surfaces. The accuracy of airfoils (blades, impellers, wings, rudder, flaps, slats, aileron and canards) has a very large impact on aerodynamic performance in subsonic, transonic and supersonic areas.

Wind tunnel tests are experimental support for the development and design of new aircraft or missile, used to verify the theoretical aerodynamics calculations. Models for wind tunnel tests are a special class of free-form surfaces. The assumption of similarity is the starting point for all experimental aerodynamics tests [2]. The most important requirement is the geometric similarity between wind tunnel model and prototype airplane. Geometric similarity can be checked only by using specialized developed method of coordinate metrology.

Most of the wind tunnel models are scaled in relation to the prototype aircraft. In rare cases wind tunnel models are not scaled. Regardless of whether it is scaled or non-scaled, geometric accuracy of wind tunnel models is very high. For wind tunnel models are defined two types of tolerances [3]:

- 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 carrier (sting).

The wind tunnel model is scaled but aerodynamic tolerances are not obtained by simple scaling prototype airplane tolerances. Tolerances of wind tunnel models are much narrower. Inverse is also true: prototype airplane tolerances are not a simple multiplication of wind tunnel model tolerances. They are much wider.

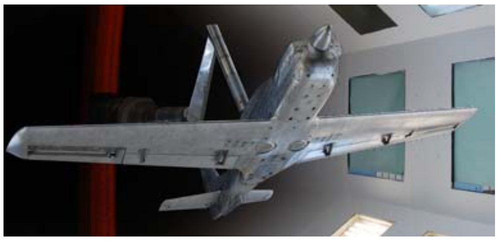

Fig. 1. Model of airplane LASTA-2 (scaled 1:5) in large subsonic wind tunnel T-35 (MTI Belgrade, Serbia)

Aerodynamic tolerances of model shown in figure 1 are a good explanation of prior consideration. For model whose wingspan nearly 2m aerodynamic tolerances are [3]:

- Overall length 1593± 0.50 mm
- Fuselage profile ± 0.25 mm
- Wing Span 1940± 0.20 mm
- Wing Root Chord 358± 0.10 mm
- Wing Tip Chord 215± 0.10 mm
- Wing Setting Angle +2° ± 0.10°
- Wing Dihedral Angle +3°± 0.10°
- Wing Tip chord twisting +3,5°± 0.05°
- Airfoil (NACA 63_2-415) deviation ± 0.05 mm
- Airfoil thickness ± 0.10 mm
- WRP position ± 0.20 mm
- Tail-WRP angular relation ± 0.10°

Inspection of wind tunnel model's geometry has two aspects: first is the final inspection prior to wind tunnel testing and second aspect is series of geometric inspection during the manufacturing process.

CMM report is final evidence of model's quality and geometric similarity between wind tunnel model and prototype airplane.

2. RELATED WORKS

Extensive studies [4] as well as the report [5], the verification of the accuracy of the airfoils geometry are done in only one section. In several cases the deviations leading edge and trailing edge multiple times exceed the tolerance. The authors note [4]: "*the wind-tunnel data may not be an accurate representation of the true airfoil performance*". For a 1.9m wing span and 0.6m chord length [5], measurement of only one section is insufficient for any conclusions.

Optical measurement system based on photogrammetry is presented in paper [6]. Inspection system, simply called "*WinGS*" (Wing Geometry Sensor), consists of two CCIR video cameras and a fringe projector. System software analyzes geometric deviation of the measured model surface with respect to the CAD design reference. "WinGS" need five reference points for the orientation of the optical measurement system. For this purpose it is necessary to put in pre-drilled holes metal plate with five retro reflective targets. System is a great help to the worker during the final polishing by sand paper, but no numerical calculation of position deviation.

Presented optical system in the paper [7] is very similar to the previous one. Various fringe patterns are project onto the wind tunnel model surface. Deviations from CAD geometry are shown in gray-color gradients over the whole wind tunnel model, but no numerical calculation of position deviation.

Optical measurements wind tunnel models using laser scanning method are presented in paper [8]. This inspection system use triangulation technique to determine the coordinate position of points on the wind tunnel models surfaces. The CMM, with a touch trigger probe, is used only for positioning reference points over the wind tunnel model surfaces. All scanned data are exported as an electronic 3D point cloud and compared with CAD file. Measured geometry could be a good basis for advanced calculation. It is necessary to distinguish "form deviation" and "position deviation".

Comparative analysis of two optical systems by airfoil measuring in the laboratory condition, geodetic tachometer and photogrammetry, is presented in the paper [9]. Wing segment was measured as an object of unknown geometry. CAD files obtained by Reverse Engineering were compared. Authors have presented the advantages and disadvantages of both systems: price, speed, environmental condition dependence, points cloud density and accuracy. The conclusion of the authors is the difference between the two methods not exceeds 2 mm which is satisfactory accuracy for aircraft measuring. This excellent analysis would be complemented with a comparison with the native CAD.

The issue of uncertainty of the position and orientation of large scale aircraft assembly (wing - fuselage) was considered in the paper [10]. Although considered objects of large dimensions compared to models for wind tunnel testing, the developed methodology can be applied to this class of aerodynamic surfaces.

The starting point is a previously defined KMC (key measurement characteristics) concept. According KMC, the assembly datum is defined as a set of geometrical features with optical target points (OTP). In the simulation model, the position and orientation of the wing-fuselage is determined by measuring OTP. The developed mathematical model applied over the set of measured coordinates of OTP. Paper [10] considers uncertainty of the wing position, but only by measurement the upper side of the wing.

Combination of optical and contact measurement method presented in the paper [11]. Combining overcome the disadvantages of both methods. The wing model defined with DU96-W-180 airfoil was measured in seven sections with the CMM. CMM measurements of the airfoil provide high accuracy in the chord direction and low accuracy in the cross direction. In the next step, the upper and lower surface of the wing was measured by optical method based on photogrammetry. The result is points-cloud with measured 3D coordinates of the wing model. These two sets of measured coordinates are combined using the Bayesian methods. The resulting 3D model represents the measured wing using two different techniques. The result is redesigned wing compared to the original CAD model.

3. ADVANCED APPROACH

Previously analyzed papers do not distinguish "form deviations" and "position deviations". To make the results of the measurements were correct these deviations should be separated. For example, if wing semi-span is 1000mm and allowed dihedral angle deviation is 0.1°, position deviation of wing tip is 1.745mm. This value greatly exceeds the form tolerance of ± 0.05 mm. Possible are completely mistaken conclusions.

Any deviation beyond a defined angular tolerance for dihedral angle and wing setting angle greatly affects the results of wind tunnel testing. Flaps and ailerons deflection angles cannot be measured by previously analyzed methods.

This paper presents the determination the position in space by measuring the upper and lower side of the wing. The measurement result is the WRP (Wing Reference Plane) that accurately defines the position of the wings in the space.

Table 1. WRP transformation matrix

	X	Y	Z
	WRP OriginTranslation [mm]		
	565	0	-104
	WRP Axis Rotations		
I	0,999391	0,001826	0,034852
J	0,000000	0,998630	-0,052336
K	-0,034899	0,052304	0,998021

WRP position in space is defined by matrix [4x3]. Table 1 is a matrix for model shown in figure 1. First row is vector of origin translation. Each column in rotation matrix is cosines angles of WRP axis in absolute (airplane) coordinate system. Wing setting angle is inverse cosine of "I" component WRP X-axis. Dihedral angle is inverse cosine of "J" component WRP Y-axis. Z-axis in table 1, is vector perpendicular to wing reference plane.

Metrology identifications of complex mechanical parts, is based on following paradigm [12]: parts are manufactured (real shape) according to CAD model → measuring points are obtained using coordinate measuring machine on real geometry → actual geometry is calculated applying the same mathematical definition of geometry on measured points → report is generated as differences between nominal geometry (theoretical, obtained from CAD) and actual geometry (measured, obtained from CMM). Coordinate metrology of WRP is based on that paradigm.

Figure 2 shows a flow chart of WRP measurement. For easier consideration of the whole complicated measurement process, the flowchart has equation and the corresponding figures.

WRP measuring is based on well-known equations of analytical geometry, obtained by dividing the line segment in a given ratio. Coordinate of points w_{Ti}, figure 2, witch divide a line segment '*UL*' (position vectors u_{Ti} and l_{Ti}) in given ratio 'λ' are calculated according to vector equations (1).

$$w_{Ti} = \frac{u_{Ti} - \lambda_i \cdot l_{Ti}}{1 - \lambda_i}; (i = 1 \cdots n) \qquad (1)$$

Dividing parameter λ is defined by eq. (2).

$$\lambda_i = -\frac{|u_i w_i|}{|l_i w_i|} = -\frac{m_i}{n_i}; (i = 1 \ldots n) \qquad (2)$$

In specific case, $\lambda = -1$, equations (1) give a coordinate of midpoints, equations (3). For symmetric and non-twisted airfoil dividing parameter is always $\lambda = -1$. Calculation of WRP is simplified [13]; the theoretical and measured points also, are arithmetic midpoints, vector equation (3).

$$w_{Mi} = \frac{u_{Mi} + l_{Mi}}{2}; (i = 1 \cdots n) \qquad (3)$$

In accordance to paradigm of coordinate metrology, the measured coordinates of WRP can be obtained by applying vector equations (4).

$$w_{Mi} = \frac{u_{Mi} - \lambda_i \cdot l_{Mi}}{1 - \lambda_i}; (i = 1 \cdots n) \qquad (4)$$

Equations (1) and (4) are applied to the same set of points: Equation (1) on the set of the theoretical coordinates, obtained from CAD, and equation (4) on the set of the measured coordinates, obtained from CMM, [13].

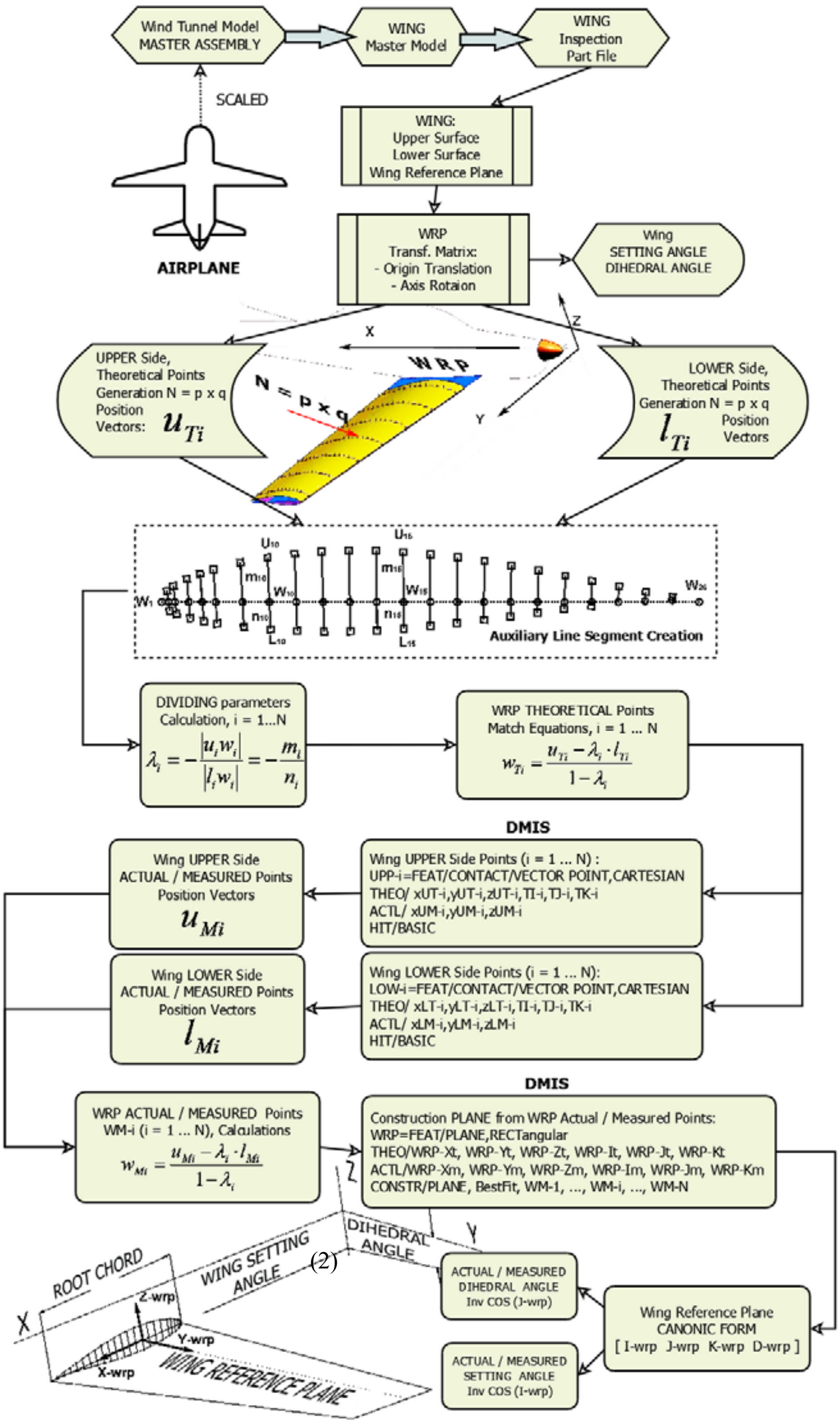

Fig. 2. Flow-Chart of Wing Reference Plane Measurement

The essence of this approach is the following: errors (form deviations) due to machining are small compared to the dimensions of the wing. If the paradigm of coordinate metrology applied to all geometric feature (prismatic, revolute, helical, cylindrical, planar and spherical) then it can be applied to free-form feature. This is the reason for applying the same set of equations for theoretical and for measured coordinates.

4. EXPERIMENTAL RESULT

Flowchart for developed method of WRP measuring is shown in the figure 2. One of the examples of implementing is the wind tunnel model shown in figure 3. It is transport aircraft half model with wing semi-span of 1893.5 mm. Model is manufactured in the MTI (Military Technical Institute) Belgrade and tested in ONERA (Office National d'Etudes et de Recherches Aérospatiales) Toulouse.

Fig. 3. Half model N2130; manufactured in MTI Belgrade (Serbia), wind tunnel testing in ONERA Toulouse (France).

Model has different dihedral angles for inboard (3.5°) and outboard (5.5°) wing. Inboard wing is measured in 4 sections and outboard wing in 8 sections. In the each of the cross-section measured between 20 and 40 points for upper and the same number for lower side of the wing, depending on the chord length. All measurement was executed at CMM with contact probe. The measured points of the upper and lower surface of the wing were the basis for the application of the developed method. Obtained results are presented in figure 4.

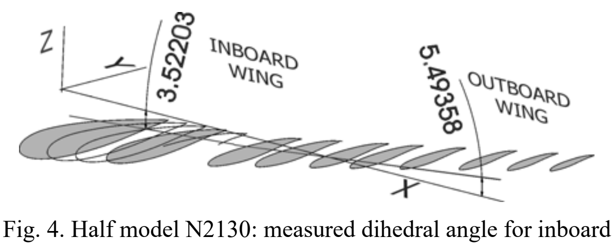

Fig. 4. Half model N2130: measured dihedral angle for inboard and outboard wing

5. CONCLUSIONS

Application of the developed method is possible on optical measuring systems also. This mathematical method would not be changed. It is differs only the number and the way of generating inspection points.

The developed method is part of the wind tunnel models production management. Developed and presented method was successfully applied on several different domestic and international projects.

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