DEVELOPED CAI MODEL FOR COMPLEX PARTS

Srđan Živković,B.Sc,M.Sc.
AERONAUTICAL INSTITUTE Žarkovo Yugoslavia

Abstract

The designing, manufacturing and inspection of wind tunnel models, requires the integration of the following stages of engineering activities in **CIM** (Computer Integrated Manufacturing) environment. **CMM** (Coordinate Measuring Machine) are basic elements of flexible automatization in production metrology. The paper describes developed **CAI** (Computer Aided Inspection) system for complex products (wings of wind tunnel models) developed as a **CIM** element. The paper pays special attention to the mathematical model for determining of the overall error as well as to the approach for the redesigning of complex surfaces based on **CMM** measurement results.

Keywords: Metrology, Coordinate Measuring Machine, Quality Assurance.

1. INTRODUCTION

Geometric model of a part is an initial element for the design process plan and the inspection plan. The development of the design system (CAD) and CIM concept lead to the development of an integrated product model, Figure 1, for the designing, manufacture and inspection. [7]

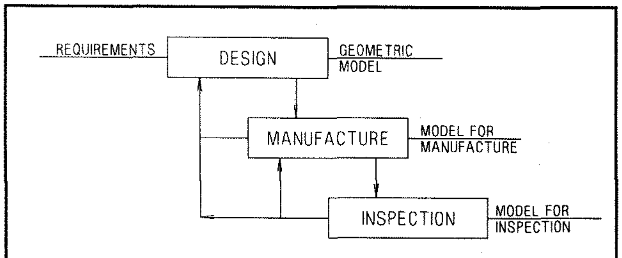

Figure 1 ***Model levels***

Present approach to the development of the quality function in manufacturing systems is based on the application of *ISO 9000* series of standards. Their application should enable the development of the **TQM** model[5] together with continuous improvement of established quality system through methods and quality engineering techniques. A particularly important segment of TQM model is manufacturing quality achieved by engineering activities in the model of concurrent engineering [6] (Figure 1) whose essential part is CAI model.

The integration of product and inspection design,[1] design process plan and inspection [2] on CMM was previously treated as a separate research task.

Today the inspection on CMM is considered integrally within CIM concept, particularly for complex surfaces.[3] As a research problem in CMM inspection there appear four research domains:

⇒ inspection plan design [4][10]
⇒ the generation of measurement sensor path on the basis of the geometric model of a part [1][2]
⇒ the inspection process itself through the comparison of nominal and
⇒ measured contour and processing of results obtained [3]
⇒ redesign of geometric model of the part (reverse engineering),[11] on the basis of inspection results.

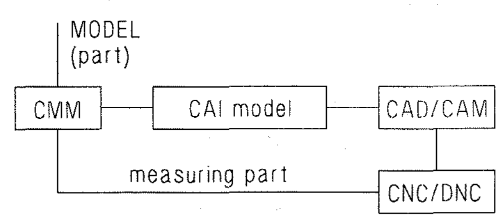

Figure 2 CAI MODEL Basic structure

All the above mentioned research problems are considered separately in practice, according to quoted authors. Our approach, presented in this paper, deals with the integration of all these tasks in CIM environment.

2. DEVELOPED CAI MODEL

Mathematical presentation and output information about the curve or a surface on a complex part primarily depend on the purpose for which this information will be used. The following are necessary and sufficient information for CAI model:

1. coordinate points on the surface (in different coordinate systems), and
2. the vector of the normal and its components for a given coordinate.

During the measurement on CMM we get the above information, and during inspection we also get the size of the error in the direction of normal's vector.

The starting point of our approach to the development of CAI model, Figure 2, was the axiom of geometric-manufacturing-metrological integration (Figure 1) as a basis for the realization of CAI model. It is an interface between CAD/CAM systems and CMM. [9]

The presented structure of CAI model enables the following approaches:

⇒ measurement (measurement object - CMM - measurement results),
⇒ inspection (measurement object - CAD - CMM - inspection),
⇒ redesigning-reverse engineering (model - CMM - CAD), and
⇒ inspection planning (CAD - CAI - inspection plan).

3. STRUCTURE OF THE SOFTWARE SUPPORT

Hardware/software structure of developed CAI model is illustrated in Figure 3.
CAD-CAM system contains the models of parts and products of complex shapes described by parameter space curves (cubic spline, Bezier curve, B-spline), as well as by complex surfaces (ruled-lofted surface, linear COON's surface, bicubic, Bezier, B-spline and tabcyl surface, as well as degenerated patch).

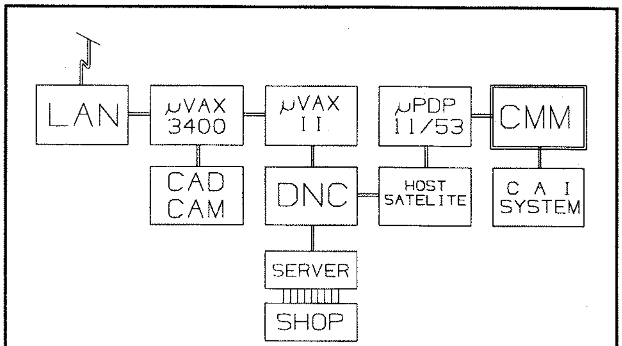

Figure 4 Hardware/Software Structure

In this way CAM module produces CNC program for 5-axis milling, Figure 4. This example relates to aeroprofile, by which the following is tested with developed CAI model:

⇒ shape, tangent's position and the symmetry of aeroprofile in characteristic sections,
⇒ aeroprofile dimensions (span radius and the thickness of the leading edge, the length of chords),
⇒ angle tolerances of aeroprofile's basic elements.

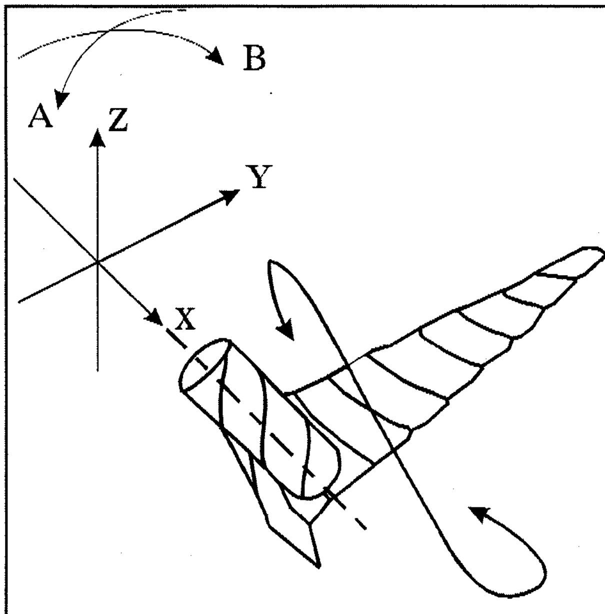

Figure 3 Five Axis Machining

The basic module of developed CAI model is the generator of inspection programsfor complex surfaces. In interactive mode the user is connecting the entities undergoing inspection through auxiliary parameters (the number of measuring sections, points density, the name of output data file, etc.). Output data file is generated after this and transferred to CMM computer, which establishes connection with CAD-CAM system through the host-satellite, for the generation of nominal features. After termination of inspection CAI system may generate data file with output results, which is later processed (redesigning of geometric model), or it may immediately produce output inspection report.

The basic menus of inspection program generators for complex parts include:

1. the definition of parameter surfaces (cylinder, conus, sphere, rotational surface, tabulated cylinder, ruled-lofted surface, limited surface, surface fillet, sculpted surface, Bezier and B-spline surface), surface sections,
2. the generation of measurement sensor path, and
3. measurement results-inspection.

A particularly important module of developed CAI system [8] is the discovery of characteristic processing errors (shape and position) on a part. The quality of obtained inspection results is also assessed with the analysis of measurement accuracy and the assessment of measurement error. Typical processing errors which this CAI model covers are:

described as bicubic parametric surface patch, so that mathematical analysis
of the overall error will be given for this type of surface. [8]

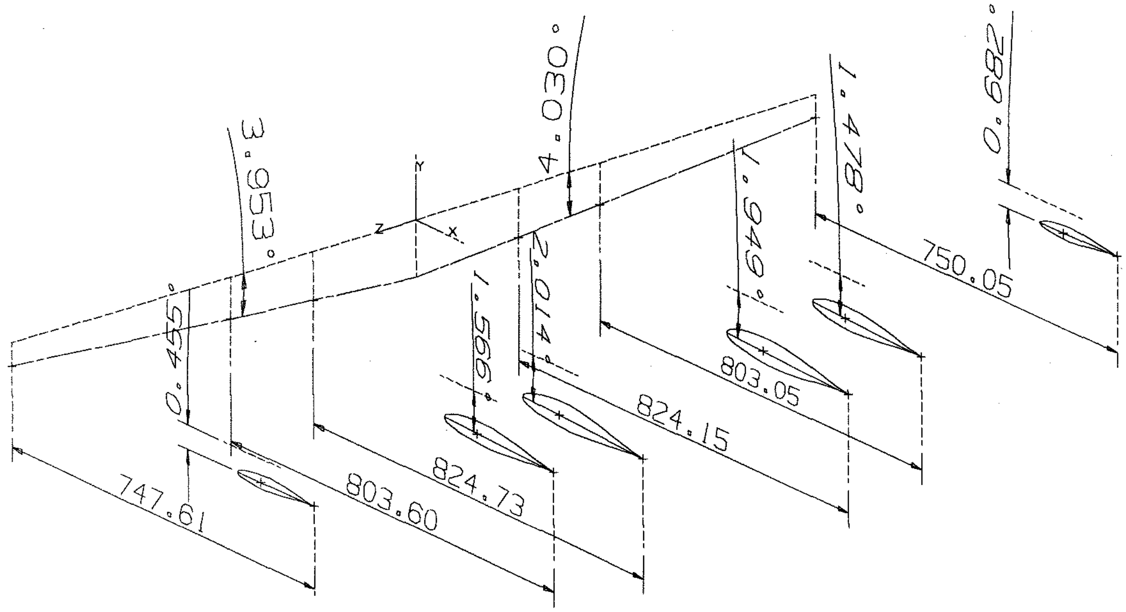

Figure 5 Inspection Results

1. tool correction errors,
2. coordinate measuring system errors,
3. equidistal surface,

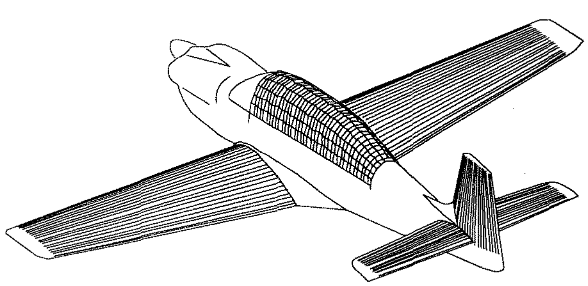

Figure 7 Airplane ***LASTA***

4. stranded surface, and
5. wear of tools.

The most frequent case is the combination of two or several processing errors,
whose identification requires complex analysis.

This paper includes the examples of inspection of the part whose surfaces are

The point obtained by the measurement of the

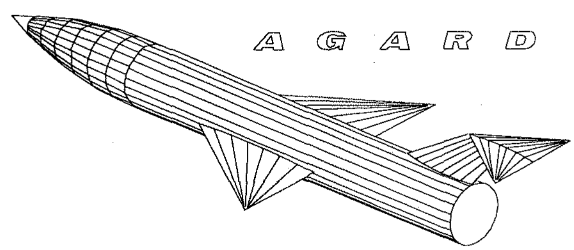

Figure 6 AGARD for Wind Tunel T-38

patch, as a rule, is not found on the surface generated by CAD system, and it is therefore necessary to find the closest point which is really situated on patch surface. The shortest distance between obtained point and the surface is found at the normal to the surface, and it represents the error (in processing, measuring) between the measured point and CAD surface.
The corresponding closest patch point may be obtained by definition of the sphere around the given point. The section of this sphere and the patch will give the closest curve on the patch, whose points

have the same distance from the given point. The minimization of this sphere's radius gives a new sphere in contact with the surface in corresponding point. In this way two nonlinear equations with unknown surface parameters **u** and **v** are obtained. Position vector of the measured point, related to the coordinate measurement system in the point is : $\boldsymbol{P} = [X_i \; Y_i \; Z_i]$, and the corresponding point has the position vector which may be written in the following form:

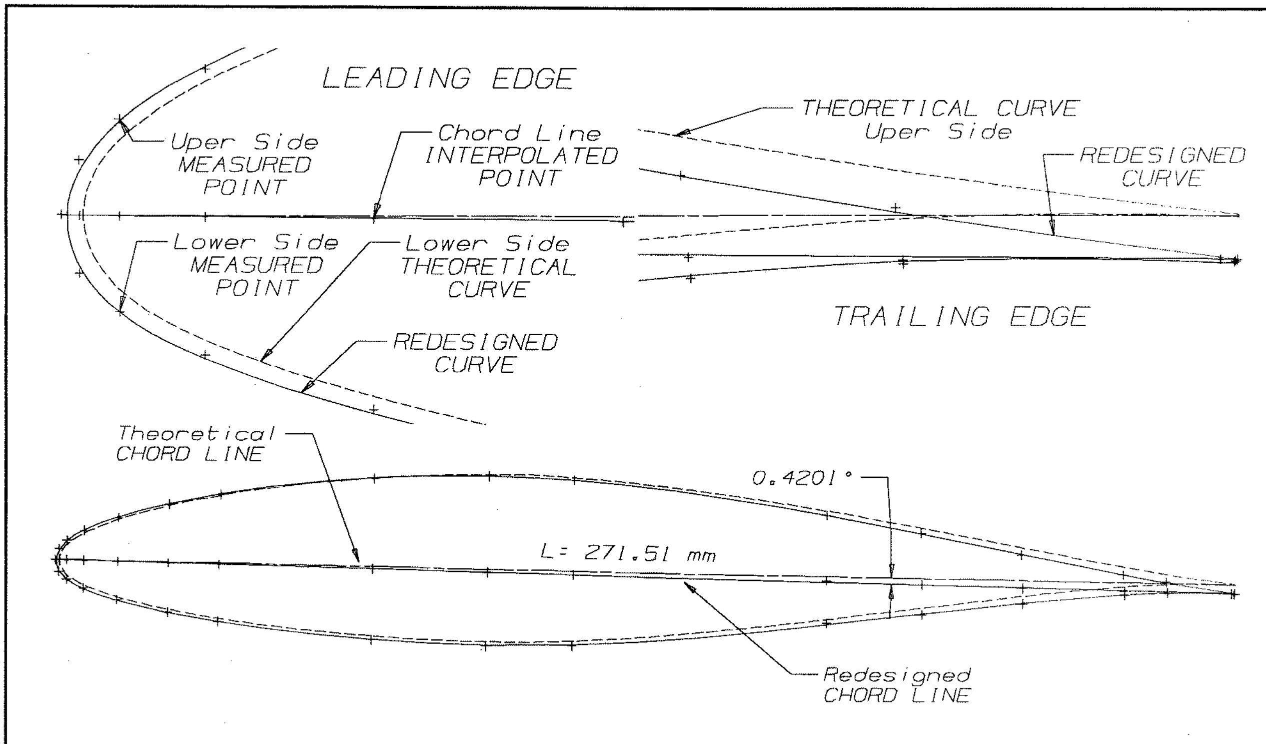

Figure 8 Airfiol redesign AERODINAMICS MEAN CHORD LINE

$\boldsymbol{P_i} = [U_i C_x V_i^T \; U_i C_y V_i^T \; U_i C_z V_i^T]$, where: C_x, C_y, C_z 4x4 are bicubic polynomial coefficient matrices.
U and **V** vectors have the following form:
$\mathbf{U} = [1 \; u \; u^2 \; u^3]$ and $\mathbf{V} = [1 \; v \; v^2 \; v^3]$.
The section of the sphere's radius ***r*** in the patch is:

$$r^2 = (U_i C_x V_i - X_i)^2 + (U_i C_y V_i - Y_i)^2 + (U_i C_z V_i - Z_i)^2 = F_{(u,v)} \qquad (1)$$

The function (1) is minimized in such a way that partial derivations over ***u*** and ***v*** are made equal with zero so that we get:

$$\vec{U}_i \, (G_x V_{iT} V_i G_{xT} + G_y V_{iT} V_i G_{yT} + G_z V_{iT} V_i G_{zT}) \cdot$$

$$\partial \vec{U}_i / \partial \boldsymbol{u} = \boldsymbol{0} \qquad (2)$$

$$\vec{V}_i \, (G_x U_i^T U_i G_x^T + G_y U_i^T U_i G_y^T + G_z U_i^T U_i G_z^T) \cdot$$

$$\partial \boldsymbol{V}_i / \partial \boldsymbol{v} = \boldsymbol{0} \qquad (3)$$

With the solution of these equations (2. and 3.) new values for ***u*** and ***v*** parameters of the corresponding point are obtained, on the basis of which now true deviation values for each individual point are determined. This was done in the example illustrated in Figure 5.

4. EXPERIMENTAL RESULTS

First measuring done on wind tunel model shown on Figure 7. Part inspection was made in three sections in relation to the model aircraft reference plane, at the distance of *210 (*near to the fuselage*) 377,52* (wing aerodinamic mean chord line) and *820*mm, (wing tip chord line) with the use of the ***aeroprofile*** option from the program generator. The inspection results are shown in Figure 5, with a graphic model of measurement results. (8)
The results obtained show deviations (within tolerance limits) for all inspection parameters:

1. the length and local geometric twist angle of the chord line
2. the thickness of the trailing edge,
3. the radius of leading edge
4. distance from aircraft model reference point and trailing edge for all section
5. effective dhiedral angle of the wing

According to the preceding analysis of errors (equations 2. and 3.) their character and their causes were determined (the error in measurement coordinate system and stranded surface).
The redesign of the geometric model generated by measurement on CMM quoted in previous example is the next experimental example (Figure 8). The redesign procedure consists from the following steps:

⇒ the generation of measurement basis (coordinates and normal vectors),
⇒ the definition of geometric model (with the aid of cubic spline),
⇒ the determination of theoretical chord and u and v parameters,
⇒ the redesign of measured and theoretical chord by linear or parabolic interpolation
⇒ the redesign of aeroprofile by cubic spline with local vectors of the normal by the method of the least square fitt.
⇒ the formation of the data base of the redesigned model.

With the use of weight functions the waving along the curve is eliminated, but the curve has to be drawn (C-spline of the same character), whose deviation squares (from redesigned and measured curve) are minimal.

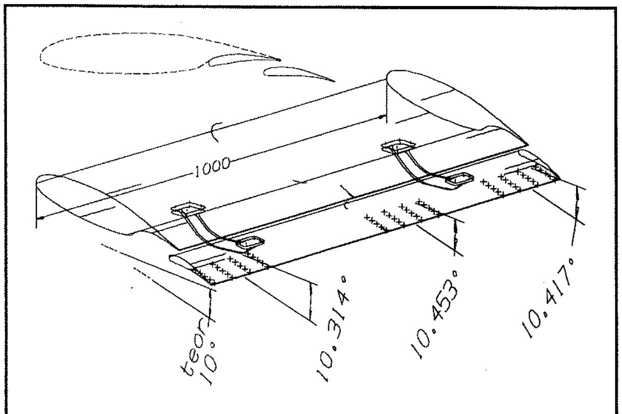

Figure 9 FLAPS 10 deegres position

The example with output report for redesigned section is illustrated in Figure 8. It contains the geometric model for the profile (measured and redesigned), as well as point coordinates for both cases.

At the end a summary review of the aeroprofile error for analyzed sections is given below. Data obtained show that the new profile is rotated in the section plane with the angle of *0.4722deg.* and translated to the overlapping points on chord's leading edge.

CURVE TO CURVE MATCHING
DEVIATION CHECKING*ERROR SUMMARY

Upper side

# OF PTS CHKD	=	39
DIST TOL	=	0.1000
#OVER DIST TOL	=	38
AVG DIST ERR	=	0.31903
MAX DIST ERR	=	0.47251
ANGLE TOL(DEG)	=	0.25000
#OVER ANGLE TOL	=	17
AVG ANGLE ERR	=	0.48101
MAX ANGLE ERR	=	9.09641

Lower side

# OF PTS CHKD	=	25
DIST TOL	=	0.10000
#OVER DIST TOL	=	24
AVG DIST ERR	=	0.62893
MAX DIST ERR	=	0.79857
ANGLE TOL(DEG)	=	0.25000
#OVER ANGLE TOL	=	4
AVG ANGLE ERR	=	0.49532
MAX ANGLE ERR	=	9.20342

Next experiment [8] was flap's angular position on 2D wing for wind tunel testing. Wing span was 1000mm. Flaps 10 deegres position are shown in Figure 9. That value is betwen flap's chord plane for zero position and chord plane for ten deg. position. For every three area was measured 20+20 points (upper and lower). Points in chord plane are results interpolating process. Chord plane was drawn thru new points. Angular differences between left (*10.314deg.*), midlle (*10.453deg*) and right (*10.417deg*) side of flaps are results of milling process. Using the same procedure measured angularity between Agard's (Figure 6) tailplane and fin. [8] The inspection results are shown on Figure 10.

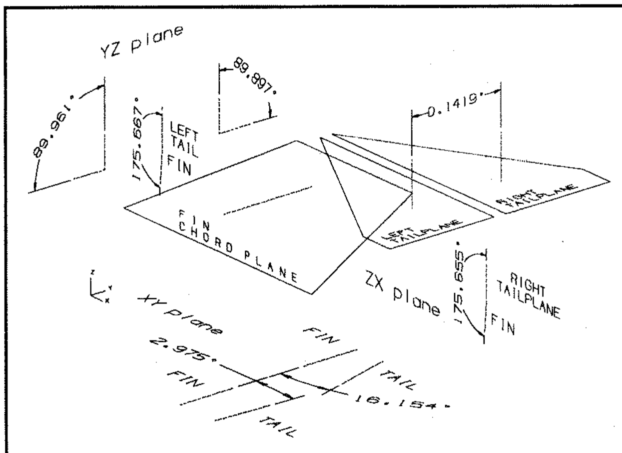

Figure 10 AGARD Angularity

5. INSTEAD OF THE CONCLUSION - FUTURE RESEARCH

Presented CAI model as a part of CIM in the present stage of development consists from the following modules:

⇒ inspection program generator,
⇒ report generator,
⇒ redesign of the geometric model
⇒ communication module
⇒ user-oriented software on CMM (axial and radial scanning of profiles and local surface and profile maximum).

The constraints of the developed model are:

1. limited number of users, and
2. off-line connection with IGES data files.

In future the research activities for further development of this CAI model will include:

⇒ the elimination of the above mentioned constraints,
⇒ the expansion of the existing basis of complex products
⇒ the development of expert system for CAI model.

This research will change software/hardware configuration of the described CAI system illustrated in Figure 4.

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