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IDENTIFICATION OF THE AERODYNAMIC COEFFICIENTS OF THE MULTIROLE MANEUVERABLE AIRCRAFT BASED ON UNSTEADY FLIGHT

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Abstract

The article describes the identification of the aerodynamic characteristics of the longitudinal motion of the maneuverable aircraft on the time domain by analysis of the data recorded in. The aerodynamic coefficients are represented as the sum of the components. The method permits to estimate each component of lift coefficient or pitching moment coefficient by itself. The aerodynamic wind tunnel database chosen as initial approximation of components. For analysis of algorithm, convergence it is used some arbitrary values as initial approximation of components the aerodynamic. The algorithm belongs to a class of Kaczmarz's projection algorithms. It enables to compute points of non-linear coefficient avoiding additional parameterization. It is presented results is processing of series of flights. Flight simulation with the estimation aerodynamic coefficient and the aerodynamic wind tunnel database was compared.

1. Nomenclature

α – angle of attack
M – Mach number
$\delta_{a.}$ – aileron deflection,
δ_H – horizontal stabilator deflection,
δ_F – leading edge flap deflection
b_A – aerodynamic mean chord
q – pitch rate
V – air speed
C_L – lift coefficient
C_m – pitching moment coefficient

2. Introduction

Modern aircraft of all kinds is a complex dynamic system with interaction between all of its subcomponents that is why final adjustment is possible only in actual operating condition. Experiments for determination of aerodynamic coefficients based on wind tunnel of scale model do not fit entirely natural flight condition. Tunnel data contamination can be significant, flight tests validation of aerodynamic coefficients is indispensable part of flight-testing experiment.

It is rational to take into account characteristics of airplane exploitation (transonic or hypersonic flights, high angle of attack flights, etc.). The choose of the data processing methodology is critical for reduce number of
experiment flights and to rise informative value significance of flight test.

Issue of identification of aerodynamic coefficients of airplane is actual in development of new aerial vehicle, flight simulators and control algorithms.

So identification of aerodynamic coefficients and parameters of airplane methodology consists of following steps:

- Development of mathematical motion model of aircraft
- Flight test planning
- Validity check of mathematical model
- Selection or development of estimation algorithm
- Result validity check

At the present moment, issue of non-linear identification is of current concern.

3. Aircraft and longitudinal model

There is a flight model of multi-role maneuverable plane integrated circuit with an adaptive wing. A large range of operating altitudes and speeds the test aircraft leads to a number of significant features in the longitudinal channel characteristic of supersonic aircraft in general[1]:

- Non-linear nature of pitching moment from angle of attack with intervals of static instability
- Decrease pitch control power when Mach number is more than 1 and on high-angle-of-attack
- Longitudinal static speed instability in transonic velocity
- Reduce of damping in pitch in high angle of attack and high altitude.

Modern integrated flight control systems bring significant influence in dynamic and flying qualities of aircraft. Research of aerodynamic coefficients complicates having of feedbacks in flight control system, ambiguous link between control stick, rudder pedals and control surfaces. There is affiliation of additional functions to flight controls (aileron droop, elevator for roll axis control on high angle of attack etc.).

All this particularities conduct to non-linear aerodynamic coefficients significantly.

In general terms, coefficients are functional relationship from kinematic parameters, similarity parameters and airplane configuration.

The aerodynamic coefficients appear in the airplane equation of motion as the sum of components. The lift coefficient is

$$\begin{aligned} C_L(\alpha, M, \ldots) &= \Delta C_L(\alpha, \mathrm{M}) + \Delta C_{L0}(M) + \\ &+ \Delta C_{L\delta_{a.}}\left(\alpha, \delta_{a.}, M\right) + \Delta C_{L\delta_H}(\alpha,\ \delta_H, M) + \\ &+ \Delta C_{L\delta_F}(\alpha,\ \delta_F, M) \end{aligned} \qquad (1)$$

where ΔC_L – lift coefficient increment, $\Delta C_{L0}(M)$ –lift coefficient increment at zero angle of attack, $\Delta C_{L\delta_{a.}}$ – aileron lift coefficient increment, $\Delta C_{L\delta_H}$ – horizontal stabilator lift coefficient increment, $\Delta C_{L\delta_F}$ – leading edge flap lift coefficient increment. These data are not measured in the flight test, so there is a need to solve the issue of identifying the components of the aerodynamic coefficients from records of the experimentally observed parameters.

The pitching moment coefficient is

$$\begin{aligned} C_m(\alpha, M, \ldots) &= \Delta C_m\left(\alpha, M\right) + \Delta C_{m0}\left(M\right) + \\ &+ \Delta C_{m\delta_{a.}}\left(\alpha, \delta_{a.}, M\right) + \Delta C_{m\delta_F}\left(\alpha, \delta_F, M\right) + \\ &+ \Delta C_{m\ \delta_H}\left(\alpha,\ \delta_H, M\right) + C_m^q\left(\alpha, M\right)\bar{q} + \\ &+ C_{m\ flx}^{c_L}\left(M, H\right) \end{aligned} \qquad (2),$$

where ΔC_m – pitching moment coefficient increment, $\Delta C_{m0}(M)$ – pitching moment coefficient increment at zero angle of attack, $\Delta C_{m\delta_{a.}}$ – aileron lift coefficient increment, $\Delta C_{m\delta_H}$ – horizontal stabilator lift coefficient increment, $\Delta C_{m\delta_F}$ – leading edge flap lift coefficient increment, C_m^q – pitch damping, $\bar{q}$ – dimensionless pitch rate $\bar{q} = \frac{qb_A}{2V}$, $C_{m\ flx}^{c_L}$ – change in the stability margin due to structural flexibility.

4. Adaptive identification algorithm

Expressions (1),(2) can be written as

$$p(t, V_x) = \sum_{k=1}^{K} d_k(t, V_x)\ , \qquad (3)$$

where $p(t, V_x)$ – is known function , for example C_L, $d_k(t, V_x)$ – any of components from right side of a sum[4].

The goal is build algorithm of estimation for $d_k(t, V_x)$ using observation results $p(t, V_x)$ on finite time interval. Employ the method of Lagrange multipliers we obtain an expression for the estimation of *k*-th component

$$\begin{aligned} d_k(t, V_x) &= d_k^o(t, V_x) + \\ &+ \frac{(d_k^o(t, V_x))^2}{\left\| d_k^o(t, V_x) \right\|}(p(t, V_x) - d^o(t, V_x))\ , \end{aligned} \qquad (4)$$

where $d_k^0(t, V_x)$ – a priory known values;

$p^0(t, V_x) = \sum_{k=1}^{K} d_k^0(t, V_x)$ – value of function $p(t, V_x)$ with $d_k^0(t, V_x)$;

$\left\| d_k^o(t, V_x) \right\|^2 = d_k^o(t, V_x)^T d_k^o(t, V_x)$ – Euclidean norm of vector

$d^0(t, V_x)^T = (d_1^o(t, V_x), \ldots, d_K^o(t, V_x))$.

5. Identification of the aerodynamic coefficients Introduction

Aerodynamic coefficient C_L is calculated based on the measured flight data and each of its components is estimated. Expression (1) can be conceived of as

$$C_L = \sum_{k=1}^{5} \Delta C_{Lk} \ . \qquad (5)$$

Draw up the components of the expression (2) vector for each time

$$\vec{C}_L = [\Delta C_L, \Delta C_{L0}, \Delta C_{L\delta_{a.}}, \Delta C_{L\delta_H}, \Delta C_{L\delta_F}], \qquad (6)$$

Values from flight test are marked ‘FT’, values from aerodynamic data bank are marked ‘AP’.

Estimation algorithm (6) is applied to the expression (5) for each time:

$$\Delta\hat{C}_{Lk}(t) = \Delta C_{Lk}^{AP}(t) + \frac{\Delta C_{Lk}^{AP}(t)^2}{\left\|\vec{C}_L^{AP}(t)\right\|^2} \cdot (C_L^{FT}(t) - C_L^{AP}(t)) \qquad (7)$$

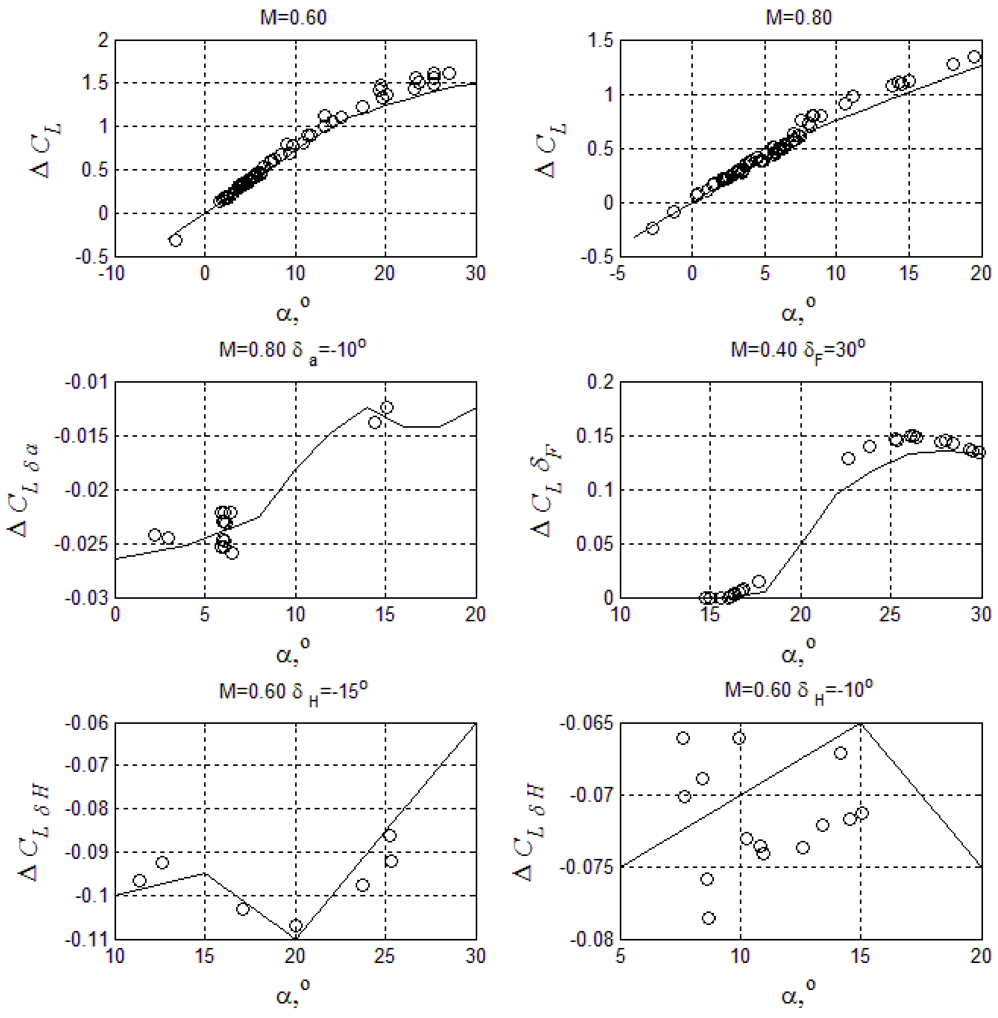

Fig. 1. Lift coefficient components. Here and beyond solid line is represented databank values , points – estimation after flight tests

Estimation algorithm for pitching moment coefficient is applied analogously.

The identification results after processing the data are recorded to the table. After that made selection results by the selected parameter (α, M, δ_H and etc.) with a given error. All the components are reduced to dimensionless quantity C_L at M=0.6, α =13°.

Estimations of aerodynamic parameters obtained with projection algorithm fairly close to the databank values almost the entire investigated range amount of prolapsed points is small.

Resulted estimations of lifting force coefficients components show the higher efficiency of leading edge flaps. Results for pitching moment coefficient components give opportunity to estimate angle of attack stability margin which was lower than apriority value in angle of attack range α=12°–17 and Mach numbers M=0.8 – 0.9

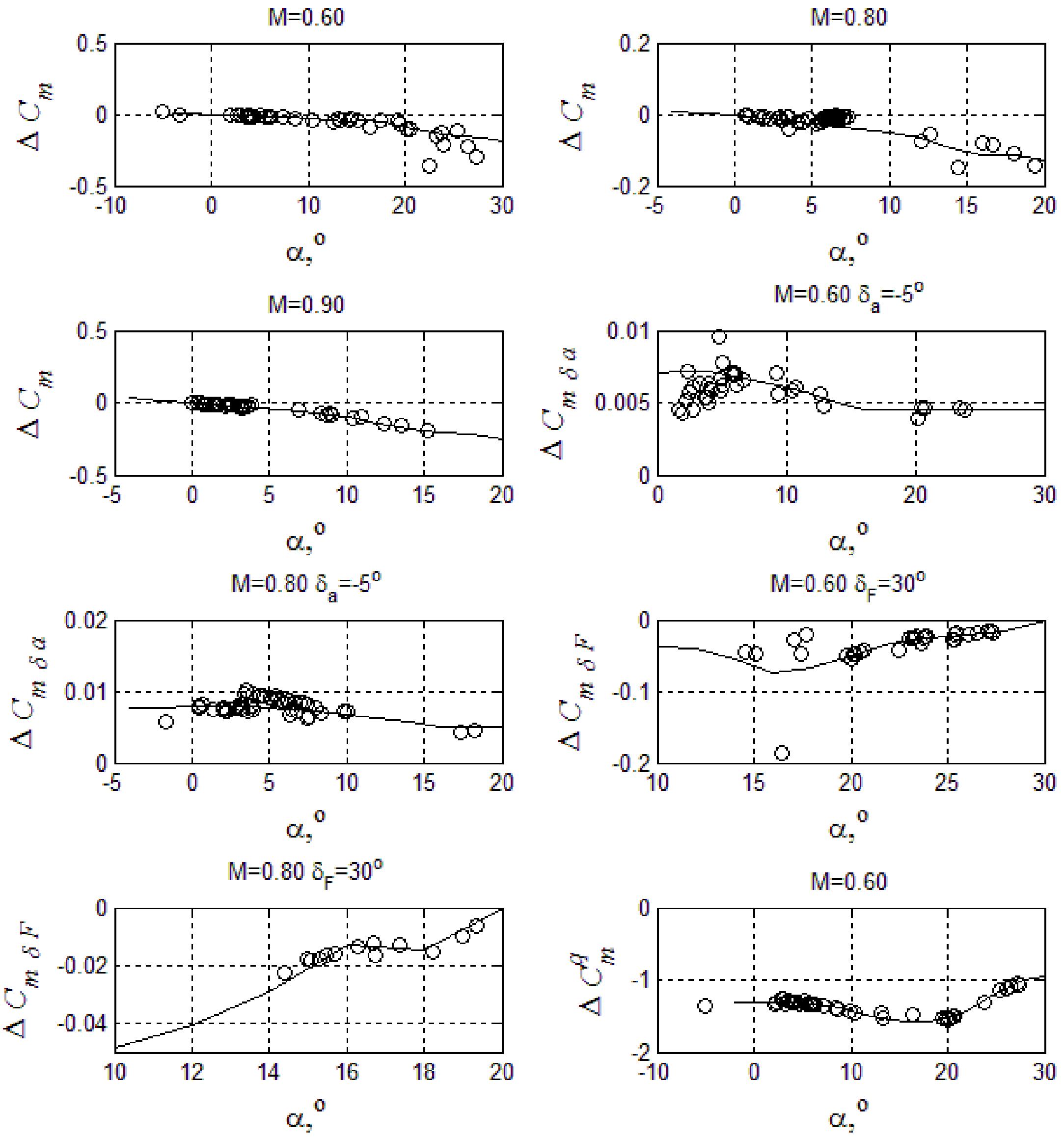

Fig. 2. Pitching moment coefficient components. solid line is represented databank values , points – estimation after flight tests

6. Convergence analysis of adaptive identification method

It is necessary to analyze dependent of estimations from a priori knowledge. In general case algorithm (4) is quick one-step method. To check its convergence algorithm is modified to iteration one. In general case, the initial conditions should use aerodynamic bank data, but in the case of convergence analysis, random values used for the first iteration

$$d_k^N(t,V_x)=d_k^o(t,V_x)+ \\ +\frac{(d_k^o(t,V_x))^2}{\left\|d_k^o(t,V_x)\right\|}(p(t,V_x)-d^o(t,V_x)), \qquad (8)$$

where N – number of iteration (N=1 in this case).

The a priori conditions should use estimates from previous step

$$d_k^N(t,V_x)=d_k^{N-1}(t,V_x)+ \\ +\frac{(d_k^{N-1}(t,V_x))^2}{\left\|d_k^{N-1}(t,V_x)\right\|}(p(t,V_x)-d^{N-1}(t,V_x)), \qquad (9)$$

where N >1.

Let us introduce a residual of estimation

$$e_N=\left|\frac{d_k^{N-1}(t,x,u)-d_k^N(t,x,u)}{d_k^{N-1}(t,x,u)}\right|$$

If the residual is small and $N\to\infty$, $e_N\to\infty$, then the iteration algorithm has convergence.

There were some sets of initial data. For example, lift coefficient increment ΔC_L was assumed to be constant,

aileron lift coefficient increment $\Delta C_{L\delta_a}$ was assumed doubled with respect to the data bank of aerodynamic characteristics, the remaining terms were assumed from the data bank of aerodynamic characteristics.

Thus, two of the five components have a significant offset from the data bank of the aerodynamic coefficients.

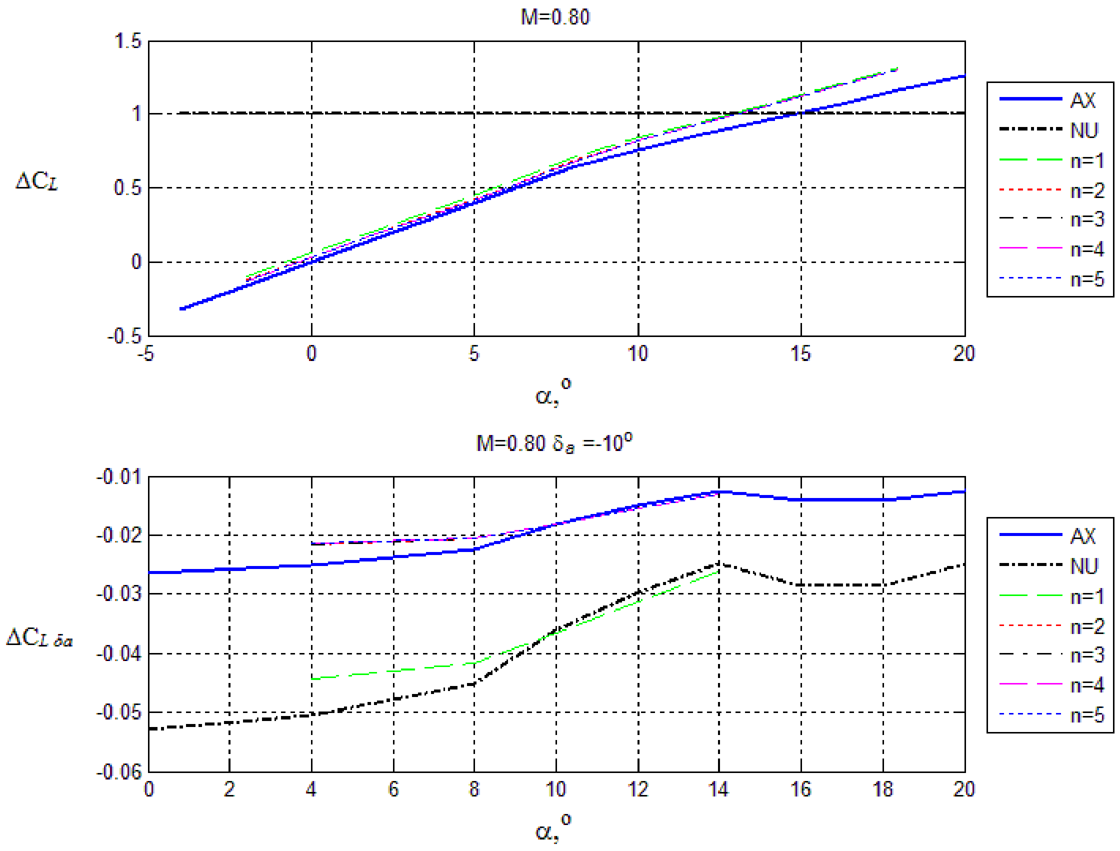

Fig. 3. Estimation of components of lift coefficient in iteration process. AX – the data bank of aerodynamic characteristics, NU – initial data.

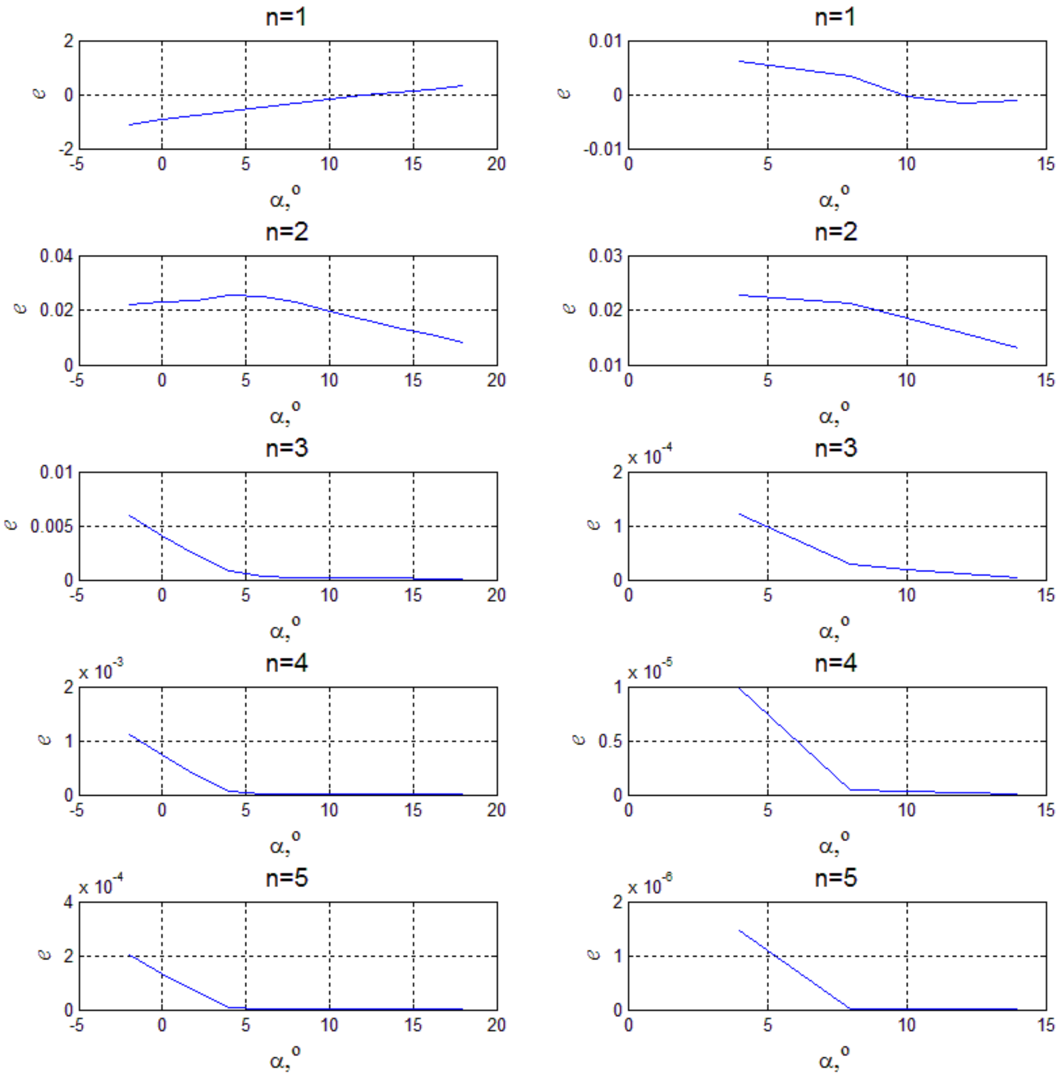

Fig. 4. The algorithm residual. n – iteration number.

These estimates are in the region of convergence at the first or second iteration. The residual decreases in each next step.

7. Conclusions

The article posed and solved the problem of identification of aerodynamic coefficients of the aircraft. Performed identification of aerodynamic coefficients components for longitudinal motion C_L, C_m with adaptive estimation method. Obtained results give good correspondence with wind tunnel data. Calculation results show that estimation algorithm have convergence when initial conditions selected in wide area across databank values. Algorithm can be named fast method as it falls to convergence area at first iterations. The advantage of this method is that motion of the studied system is not restricted with some preselected signals so algorithm i.e. method can used for data from unstable evolutions of system.

The results suggest the possibility of a successful application of projection algorithm for tasks of aerodynamic characteristics estimation.

The estimates obtained are recommended for correction of databank values.

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