ANALYSIS AND EXPERIMENTAL VALIDATION OF AN AEROELASTIC HALF WING MODEL

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1 Introduction

Efforts described in the submitted paper relate to the 5th FP EC project "Active Aeroelastic Aircraft Structures" (3AS) - [1]. The main aim of the 3AS project has been to employ aeroelastic characteristics of the aircraft structure to increase the operational efficiency of the structure.

This contribution concerns adaptive deformations of the structure by means conventional and new aerodynamic control surfaces.

2 Task aim

The main aim was to research and verify the Active Aeroelastic Wing Tip Control (AWTC) on the half wing component of the European Research Aeroelastic Model (EuRAM) with the active control off and on.

During the initial analysis and wind tunnel test the flutter with the outer engine horizontal bending dominant mode was detected. The wing tip control surfaces haven't been effective for this type flutter suppression. From this reason the effectiveness of the active control device was planned to prove on the complete EuRAM and activities with the component one were focused to the basic static aeroelastic characteristics investigation. The results were used to the FE model tuning and to the planning of the activities on the complete EuRAM.

3 Tests

3.1 Demonstrator and test facilities

The component EuRAM of the right half wing of the four jet engine transport aircraft was designed and manufactured in the TsAGI and tested in the VZLU [2, 3]. The same comparative tests were performed on the left half wing in the TsAGI. Stiffness distribution of the demonstrator (Fig. 1) has been simulated by the duralumin beam. Mass and aerodynamic means of ten wing body sections. The ring engine bodies flowed by the stream have been suspended through the short elastic beams to the wing beam.

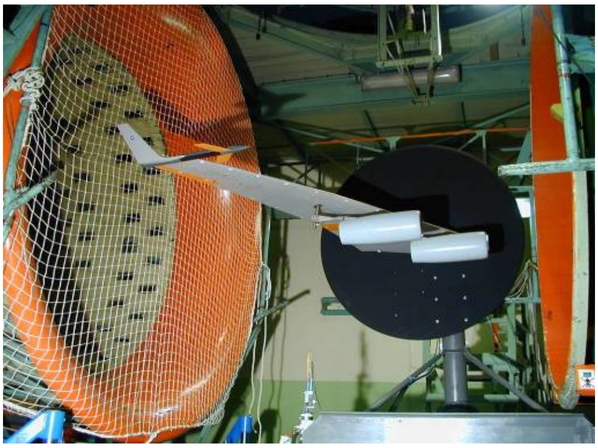

Fig. 1

The wing with the winglet has been equipped with the inboard (IA) and outboard (OA) ailerons, with the tip aileron (TA) on the wing tip and with the out-of-plane aileron (OPA). The TA and OPA can be attached to the pylon of three different lengths placed on the wing tip and under the wing plane (Fig. 2). The halves of the OPA and TA can be adjusted with forward/backward sweep.

Fig. 2

The ailerons were mechanically blocked at the static test. The ailerons were driven by miniature hydraulic cylinders through the push-pull rods at the dynamic test.

The VZLU low-speed wind tunnel is circulating one with open test area with the 3 m of the circular cross-section and the 3 m length. The maximal flow speed is 70 m/s.

At the static test the aerodynamic forces and moments were scanned with the six component strain-gauge aerodynamic balance.

Loads (bending and torsion moments) of the model structure were scanned by strain gauges in the root, half and tip of the wing.

Deformations of the model were scanned by three following methods:

– Inclinometers spanwise in three cross-sections of the wing around the elastic axis and on the outboard engine in the x-z plane;
– Optical contact less indicators (four twins spanwise, working on the principle of the distance change of the laser mark projected to the elastic model from the indicator);
– Photogrammetric method, in which the shift and torsion of the wing tip were identified from the trajectory of the points on the tip (Fig. 3).

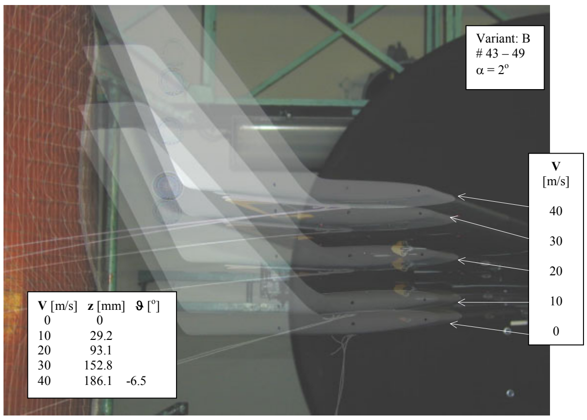

Fig. 3

At the static test the model was equipped with accelerometers on the outboard engine (horizontal) and on the wing tip (vertical) for the vibration checking.

The sampling of the strain gauge signals, accelerometers and inclinometers was 200 Hz; the optical signal was scanned with 8 Hz.

At the dynamic test the external excitation of the model was realized by the hydraulic cylinder in the attachment point of the outboard engine (Fig. 1) and by the ailerons.

Programs for the data acquisition and the excitation control were generated by the LabVIEW system.

3.2 Examples of test results

Complete stiffness characteristics were tested on the right half wing model. The flexibility influence coefficient distribution is shown in the Fig. 4.

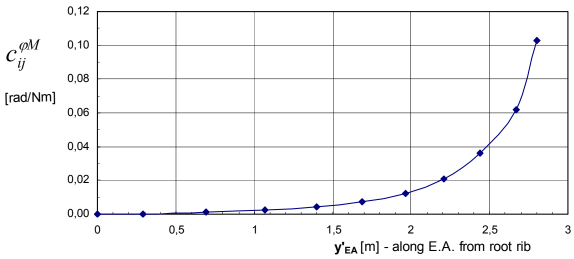

Fig. 4

Three basic demonstrator variants were tested on the stiff support before the wind tunnel test with using the PRODERA system. The natural frequencies of one variant of the left and right half wing gained from tests and analysis are presented in the Table 1.

There is the comparison of the lift effectiveness c_L^{δ} of right half wing aileron variants as example in the Fig. 5.

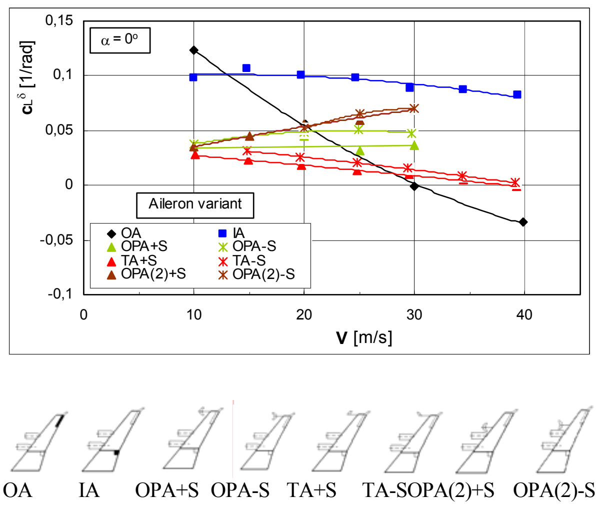

Fig. 5

There are dependences of the vertical bending moment M_x in the wing root on the flow speed V at nine levels of the angle of attack α in the Fig. 6. The load envelope was used for the on-line monitoring of the demonstrator protection. The tunnel run was interrupted when the given value of the moment was reached.

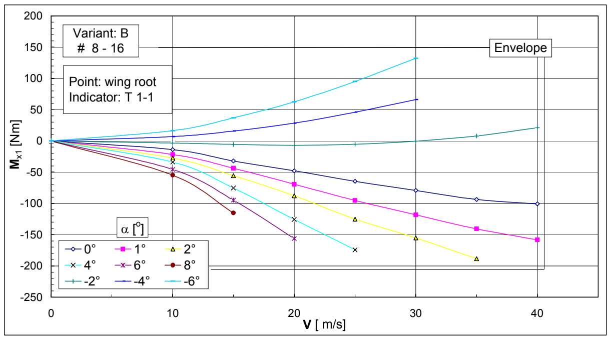

Fig. 6

The twist angle φ around the elastic axes obtained by means of inclinometers is presented in the Fig. 7.

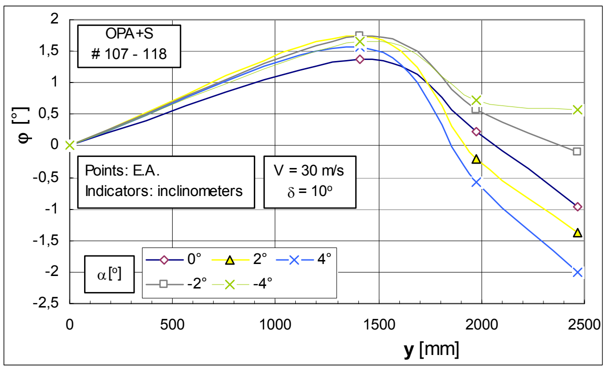

Fig. 7

Results of flutter tests are mentioned in chapter 4.4.

4 Analysis

4.1 Description of mathematical models

To perform analytical researches of different active aeroelastic aircraft concepts the mathematical models of wing were created in NASTRAN and ARGON software [4].

The NASTRAN finite element (FE) structural model of half wing was built on the basis of drawings of the EuRAM wind tunnel (WT) model. The main requirement at development of the FE model was high-accuracy simulation of stiffness and mass characteristics of manufactured WT model. Creation of the FE model was accomplished mainly by using beam finite elements. Stiffness of the WT wing spar was modelled by beam elements. Beam elements with pinned degrees of freedom were used for the correct description of the kinematics of aircraft control surfaces. The rod element was used for modelling of elastic connection between the wing and the aileron. Twodimensional quadrilateral and triangular elements were added to the FE model to improve visualization in post processing. These elements for each compartment are connected with spar only in one node. The engine pylon was simulated by five beam elements with real stiffness characteristics and distributed masses. The spar mass properties were described by specifying the mass density of aluminium alloy for the spar elements. Mass parameters were also modelled by means of eleven concentrated masses with relevant moments of inertia for simulation of compartment masses. Concentrated mass elements were used to specify mass properties of engines. The FE model of the half wing is presented in Fig. 8.

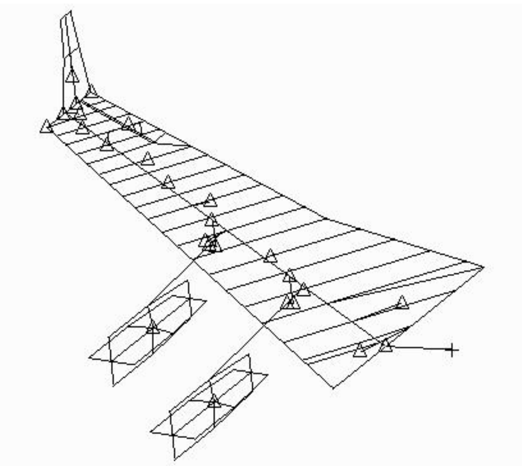

Fig. 8

Structural analysis model in ARGON software is based on Ritz polynomial method [5] and can include beam, panel, plate and mass elements. In our case the half wing structure was modelled by beam and mass elements with the same stiffness and mass properties as in the NASTRAN model.

Two variants of attachments of AWTC to wing were considered. In the first variant the AWTC with only one lifting surface was attached to the end of wing spar, and in the second variant the AWTC (with symmetrical or anti-symmetrical location of lifting surfaces) is attached to the wing spar at the middle point of ninth compartment. Finite elements of the AWTC model at the end of the wing spar are shown in Fig. 9. Three distances of the location in forward direction for both cases are considered. Also the FE models for

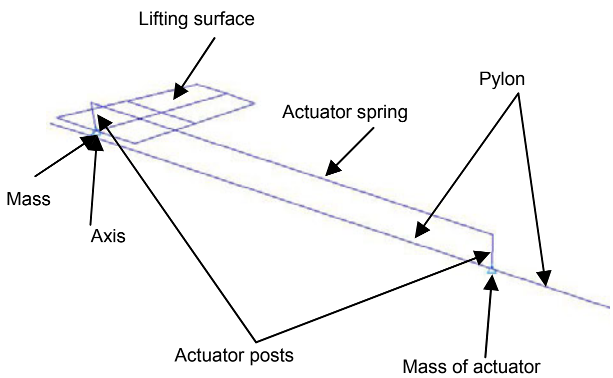

Fig. 9

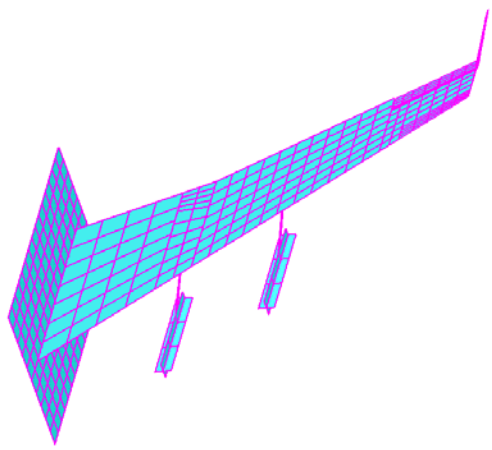

Fig. 10

two positions of out-of-plane AWTC are prepared. The pylon lengths in vertical direction for these models are equal 65mm and 115mm correspondingly.

Aerodynamic models both in NASTRAN and ARGON were created for the half wing (including winglet) with the separation plate to simulate the WT tests. Doublet–lattice and panel methods were used for modelling of airflow. The ARGON aerodynamic model is presented in Fig. 10. Coupling between the aerodynamic elements and the structural model was accomplished by beam splines.

4.2 Modal analysis

The modal analysis in NASTRAN system was performed to verify stiffness and mass characteristics of the wing by comparison with experimental results.

Natural frequencies obtained by analysis together with experimental ones for right wing (VZLU) and left wing (TsAGI) for the first ten modes are presented in the Table 1.

Table 1.

	Mode description	GVT, VZLU	GVT, TsAGI	Analysis
1	1st vertical bending	1.629	1.70	1.72
2	1st inn. eng. hor. vib.	2.713	2.70	2.56
3	2nd vertical bending	3.239	3.00	2.96
4	1st out. eng. hor. vib.	3.372	3.29	3.29
5	1st inn. eng. vert. vib.	4.212	4.19	4.03
6	1st horizontal bending	4.655	4.68	5.02
7	1st out. eng. vert. vib.	5.365	5.36	5.85
8	2nd inn. eng. hor. vib.	8.430	8.21	8.97
9	2nd out. eng. hor. vib.	8.482	8.43	8.81
10	3rd vertical bending	10.27	10.3	12.3

It is worth to note that the experimental and analysis results are in satisfactory agreement with each other.

4.3 Static aerodynamic coefficients

The aeroelastic calculations for the prediction of the influence of the structural elasticity on the aerodynamic coefficients were done by ARGON software. Lift curve slope versus airflow speed is presented in Fig. 11 for both analysis and experiment. As can be seen the agreement between these results is very good.

Fig. 12 shows analytical and experimental results at control by traditional aileron for roll moment curve slope versus airflow speed. The experimental results for both left and right wings tested correspondingly in TsAGI and VZLU are slightly different from the obtained ones by analysis.

The same results at control by the wing tip aileron are shown in Fig. 13. The experimental

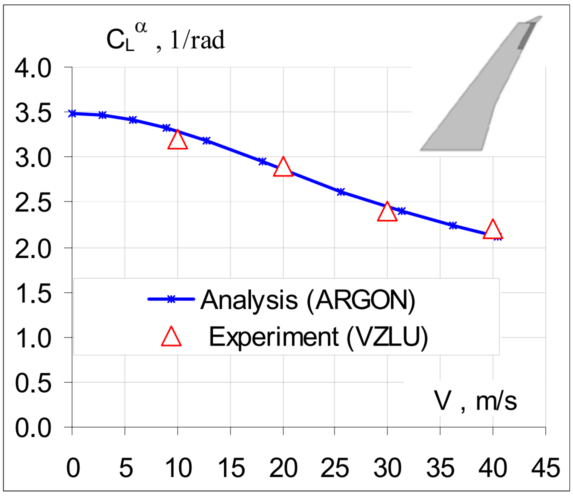

Fig. 11

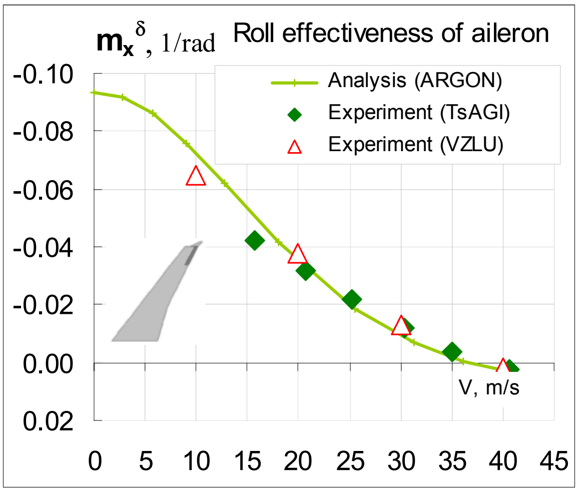

Fig. 12

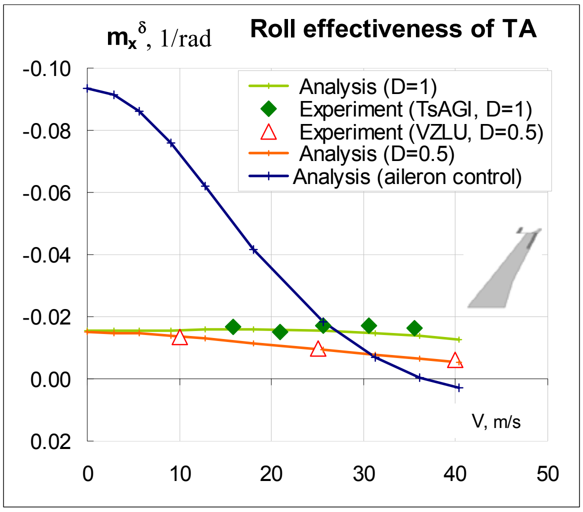

Fig. 13

and analysis results are presented for two different distances of the TA location in forward direction (D = 1 corresponds to one wing tip chord and D = 0.5 – a half of wing tip chord). The roll effectiveness of the TA is not practically changed when airflow speed increases whereas the roll effectiveness of the traditional aileron fast reduces with the increase of airflow speed.

4.4 Flutter

A set of flutter analyses for different configurations of the wing was performed by NASTRAN program. It was found that the most critical flutter modes are related with the engines vibrations.

The engines position has the most important influence on the flutter speed. The least flutter speed corresponds to the maximum down and maximum forward position of the engines. The flutter speed obtained from the analysis was 24 m/s and the dominant critical mode was the lateral bending of the outboard engine with frequency 3.15 Hz. The experimental flutter speed is slightly higher – 26.5 m/s with practically the same value of the frequency.

5 Conclusions

The submitted contribution has been resumed the results concerning the experimental and theoretical verification of the usage of wing structure adaptive deformations by means of conventional and new aerodynamic control surfaces to increase of the operational efficiency of the aircraft.

Tests of the half wing EuRAM demonstrator were performed in the VZLU (right half) and in the TsAGI (left one). The analysis with using the NASTRAN and ARGON codes was performed in the TsAGI.

The experimental and analytical results of the component wing model were compared and used mainly to the FE model verification and for the correction of the activities on the complete EuRAM.

6 Acknowledgements

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