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X-DIA DEMONSTRATOR AEROELASTIC TEST – DESIGN, ANALYSIS AND MODEL WIND TUNNEL SUPPORT TUNING

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Summary: *Submitted paper deals with preparation of the X-DIA aeroelastic demonstrator component wind tunnel tests. Paper is focused to design, analysis and manufacturing of new composite foreplanes, FE analyses of the X-DIA Component Model (static aeroelasticity, flutter, dynamic responses) and optimization study of the demonstrator wind tunnel support device. Analyses were performed by means of the MSC.NASTRAN program system.*

1. Introduction

The VZLU Aeroelasticity Group was involved in the 5^{th} FP EC project "Active Aeroelastic Aircraft Structures (3AS)" during the 2002 - 2005. The main aim of the 3AS project was to employ aeroelastic characteristics of the aircraft structure to increase the operational efficiency of the structure (increasing performances, decreasing of the aerodynamic drag, structural weight, control surface size etc.). A several concepts and approaches were researched and evaluated.

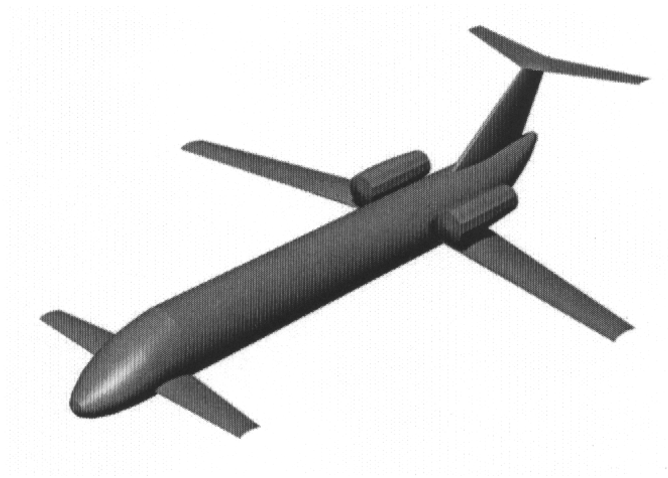

Fig.1 – Demonstrator X-DIA (initial state)

The "Active All - Movable Foreplane (AAMFP)", concept was validated by means of the X-DIA demonstrator (fig.1). Main aim of the task was development and validation of the damping system of fuselage vibrations by means of the foreplane active control. The demonstrator was adapted from older RPV (Remotelly Piloted Vehicle). New flexible fuselage (Politecnico Milano) and two types of new foreplanes – forward swept (DLR) and backswept (VZLU) were designed and manufactured. Experimental validation was divided into two parts; the X-DIA Component Model (front fuselage and foreplane) was tested in the VZLU ∅ 3 m wind tunnel, X-DIA Complete Model was tested in the PoliMi 4 x 4 m wind tunnel.

2. Design and Manufacturing of New Composite Foreplane

Design of new foreplanes was started by the introduction analysis study, which was performed in cooperation of VZLU and DLR. Many calculations, especially aerodynamic

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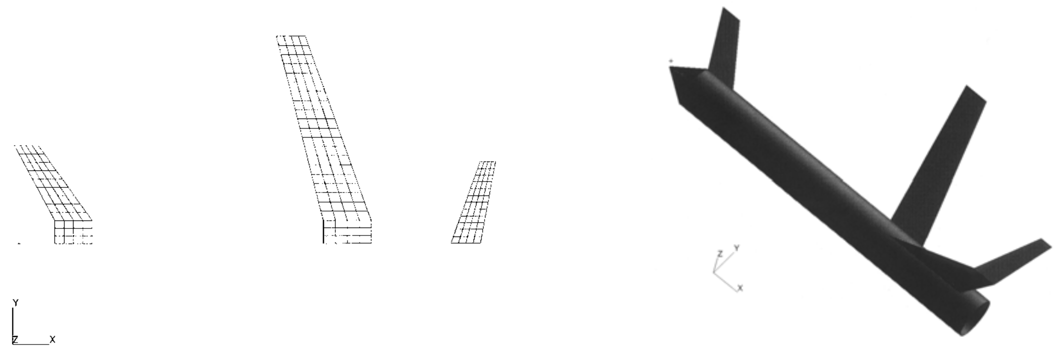


Fig.2ab – Analysis models (LIFTING LINE, NASTRAN)

loads distributions, were performed in the frame of mentioned study to set optimal geometric parameters of foreplanes. Calculations were performed by means of the LIFTING LINE system (Vortex Lattice aerodynamics – fig.2a) and NASTRAN (Doublet – Lattice and Wing – Body Interference – fig.2b aerodynamics). Examples of results (lift coefficient spanwise distributions) are shown in the fig.3abc for the backswept foreplane. Fig.3ab show the same results given by two different models, fig.3c shows influence of interference with the fuselage.

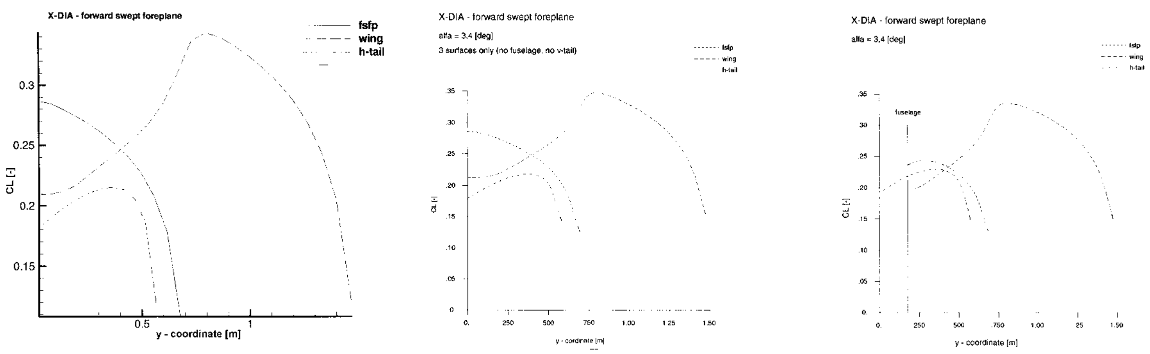


Fig.3abc – Lift coefficient spanwise distribution – backswept foreplane configuration (LIFTING LINE, NASTRAN – DLM, NASTRAN - WBI)

Final geometric dimensions set on the basis of presented calculations are shown in the fig.4ab. From the technological reasons, the symmetric Eppler 169 profile was selected. The backswept foreplane (model A) was manufactured by the VZLU, the forward swept one (model B) by the DLR.

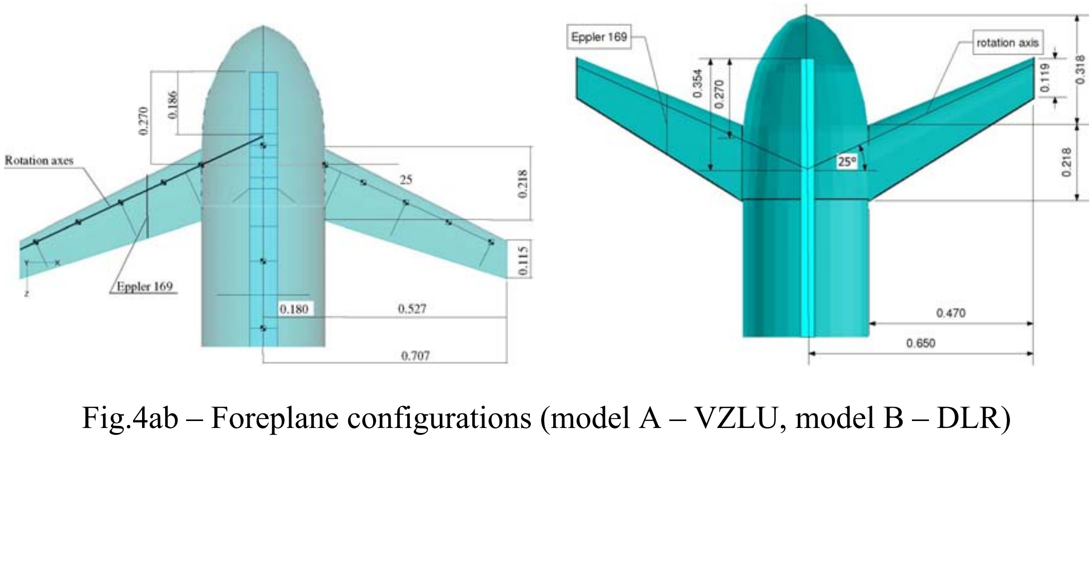


Fig.4ab – Foreplane configurations (model A – VZLU, model B – DLR)

Backswept foreplane (model A) was designed according VZLU experiences as one spar (U – cross section) composite structure with three ribs (root, tip, helping) and load bearing skin. Bending moment and shear force are carried into two ribs (root, helping) by the connecting tube and torque moment is carried into root rib by the hub. The best image concerning the foreplane design is given by design model drawings, which are presented in the fig.5ab.

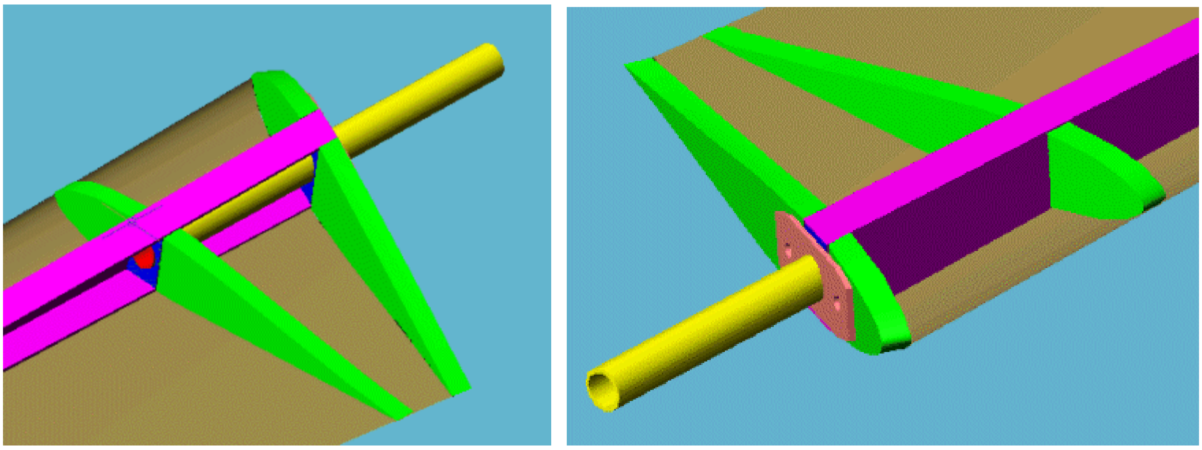
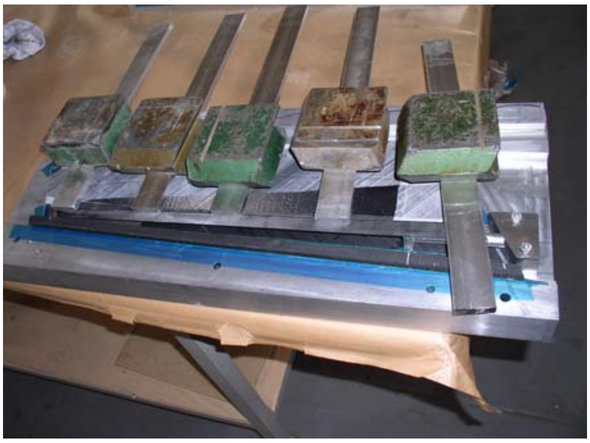
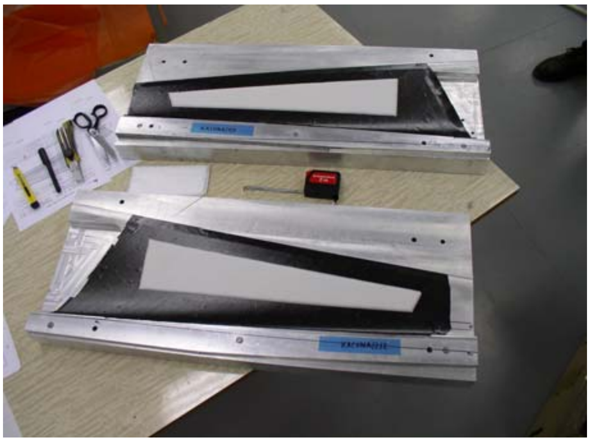


Fig.5ab – Foreplane design model drawings

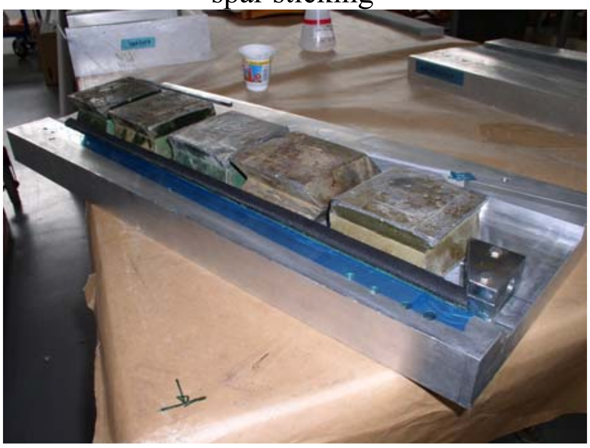
Aerodynamic loads for the foreplane strength checking were obtained by means of the NASTRAN static aeroelastic analysis. The foreplane mass and stiffness characteristics were firstly estimated the same as for the initial foreplane. During the design process were replaced by the actual values.



spar sticking



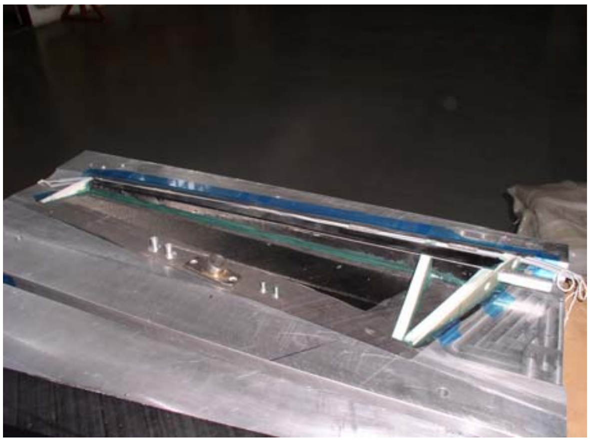
skin foam stiffening

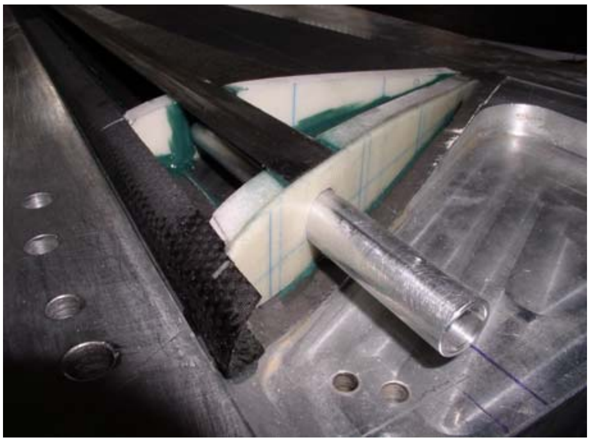


leading edge overlap sticking

ribs

Fig.6abcd – Foreplane manufacturing





assembling root part detail

Fig.6ef – Foreplane manufacturing

Tab.1 – Foreplane manufacturing – list of used materials

material name	material type	usage
Stesatape EP121-CR508/130-35	1 directional C / E composite	load bearing parts
Fibredux F913C-926-40%	2 directional C / E composite	leading edge overlap
Stesapreg EP112-68-37	2 directional G / E composite	ribs
Rohacell 71 IG	foam	ribs
Airex R82.80	foam	skin stiffening
Steel	metal	tube / ribs interface
Duralumin	metal	connecting tube

Fig.7 – Foreplane final state

Foreplane was made of several types of composites, foams and metallic parts. Manufacturing procedure is documented in the fig.6a-f. The foreplane skin was stiffened using foam in the part between the helping rib and the tip one and by additional composite layers in the leading edge part. The list of used material is presented in the tab.1.

Each half-foreplane was equipped by the accelerometer at the tip part. Almost final state of the foreplane model A, just only with no tip ends is shown in the fig.7.

3. X-DIA Component Model FE Calculations

Aeroelastic analyses of the X-DIA Component Model (fixed front fuselage and foreplane) were performed by means of the NASTRAN system. FE model was updated according the new foreplane geometry, mass and stiffness characteristics; also new values at the foreplane attachment area were introduced. FE model is a beam – like structure, stiffness characteristics are modeled via beam placed at the elastic axis of each structural part, mass characteristics are introduced as concentrated masses with appropriate moments of inertia. Aerodynamic model is based on the Wing – Body Interference Theory. Structural and aerodynamic parts are shown in the fig.8ab.

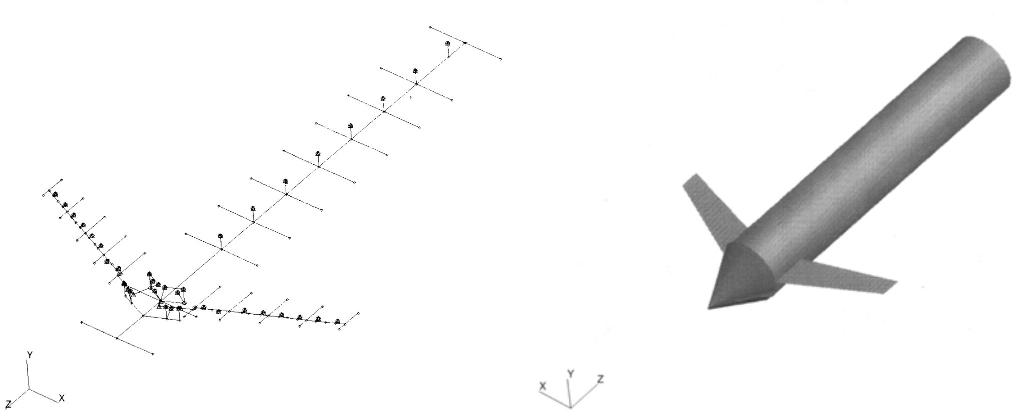


Fig.8ab – X-DIA Component Model FE model (structural, aerodynamic)

The modal analysis was performed using SOL 103, Automatic Givens Method. The purpose of analysis was to describe the modal characteristics, especially in the tested frequency range. The modal analysis results summary is presented in the tab.2, the most important modes are 1st fuselage vertical bending and 1st fuselage torsion, which were planed to damp using active foreplane control during tests.

Tab.2 – Modal analysis results summary

mode	mode title	frequency	gen. mass	gen. stiffness
#		f [Hz]	μ [kg.m^2]	χ [kg.m^2.s^{-2}]
1	1st fuselage vertical bending	4,298	6,370	4645
2	1st fuselage horizontal bending	6,015	6,490	9271
3	1st fuselage torsion	18,925	0,154	2179
4	Symmetric foreplane vertical vibration	26,213	0,118	3208
5	2nd fuselage vertical bending	39,773	0,664	41485
6	Antisymmetric foreplane vertical vibration	42,517	0,271	19328
7	2nd fuselage horizontal bending	48,924	0,164	15501
8	Symmetric foreplane horizontal vibration	59,026	0,065	8951
9	Antisymmetric foreplane horizontal vibration	65,761	0,166	28351

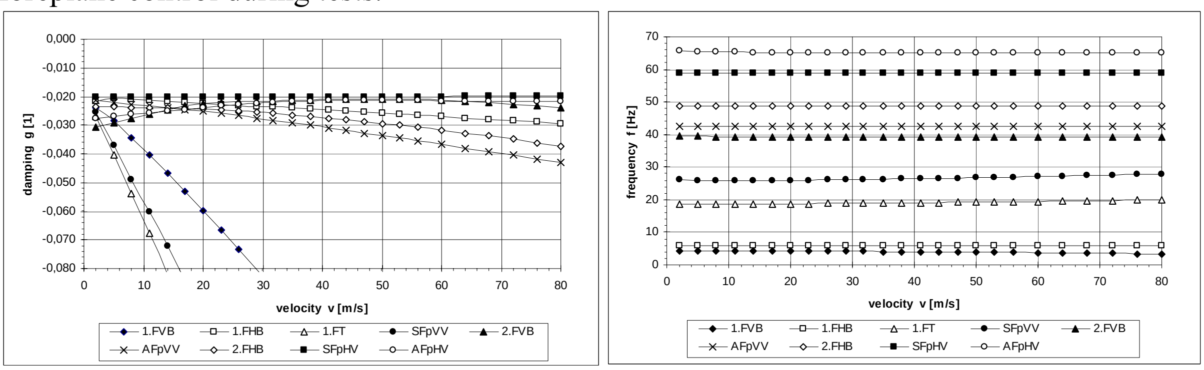


Fig.9ab – X-DIA Component Model flutter analysis (v-g-f diagram)

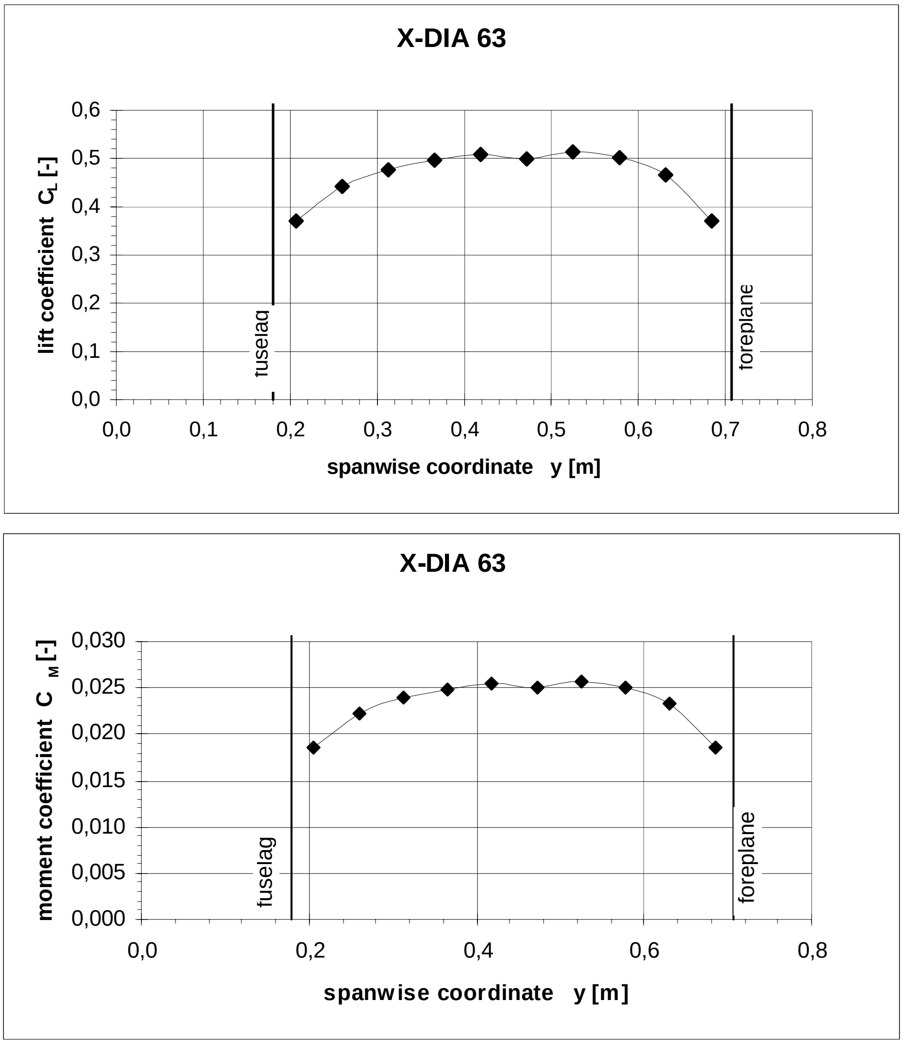


Fig.10ab – X-DIA Component Model – lift and moment coefficient spanwise distribution

The flutter stability analysis was performed using SOL 145, PK method. The purpose of analysis was to check possible flutter instabilities in the range of tested velocities. According assumptions, there was found no flutter instability. The v-g-f diagram is presented in the fig.9.

The static aeroelastic analysis was performed using SOL 144. The purpose of analysis was to obtain aerodynamic loads taking account the flexibility of the structure. Loads were used especially for the strength checking. For this purpose, the critical combination of TRIM parameters (air velocity = 55 m.s^{-1}, angle of attack = 5 deg) was selected. The lift and pitching moment spanwise distribution for the mentioned TRIM conditions are presented via the lift and moment coefficient in the fig.10ab.

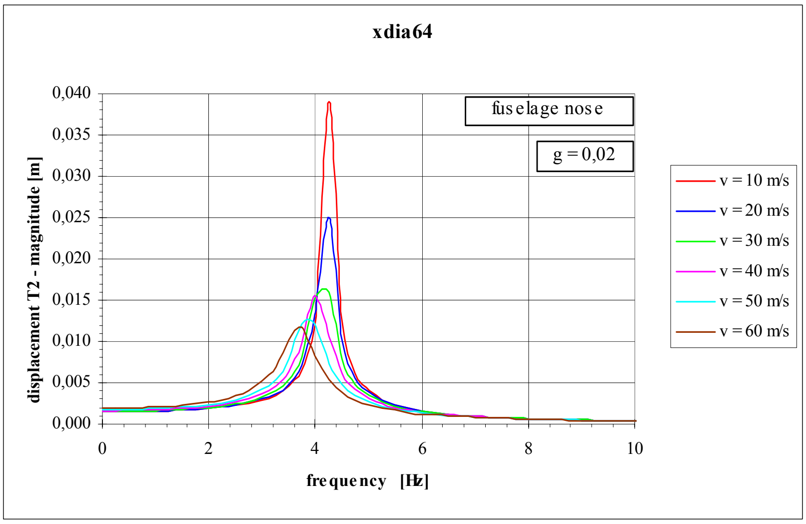


Fig.11a – X-DIA Component Model – frequency response analysis – amplitude characteristic

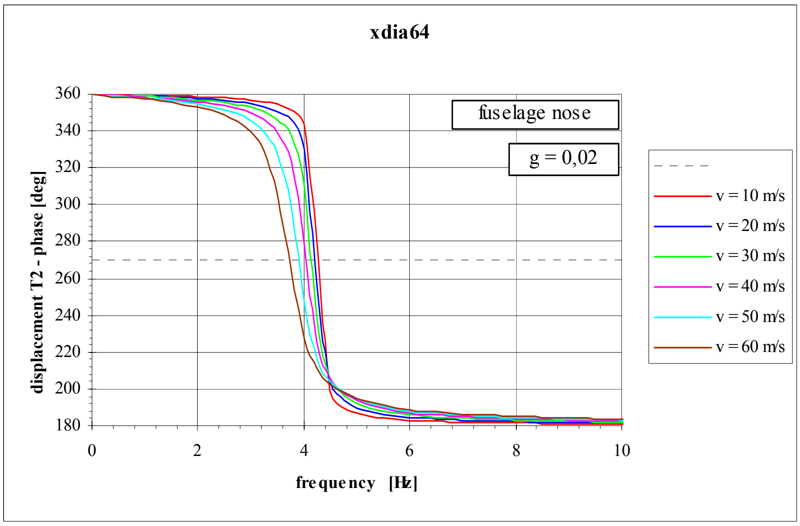


Fig.11b – X-DIA Component Model – frequency response analysis – phase characteristic

The aeroelastic response analysis was performed using SOL 146, frequency response solution. The purpose of analysis was to simulate the excitation in the wind tunnel. Force and moment excitation were used. Response of the structure was observed at several points. Example of the structure response is presented in the fig.11 via amplitude and phase characteristics, which describe the influence of the wind flow to the structure total damping (aerodynamic damping) and changes of natural frequency due to the wind flow.

4. Model Wind Tunnel Support Tuning

Installation of the model to the VZLU wind tunnel must have satisfied some conditions. There were demands of usage the original wind tunnel model manipulator and the VZLU strain gauge balance on the one side and the necessity to reach enough stiff attachment on the other side. The estimated frequency range for test was set up to 15 Hz; therefore natural frequencies of the attachment (with the X-DIA Component Model installed) were required above 20 Hz. The initial state of the wind tunnel manipulator with the

Tab.3 – Wind tunnel manipulator – initial state – natural frequencies

#	f [Hz]	description
1	13.9	1st attachment vertical bending
2	14.6	1st attachment horizontal bending
3	20.9	Attachment rotation in plane z-x
4	33.8	Attachment rotation in plane y-x
5	97.1	Attachment space bending

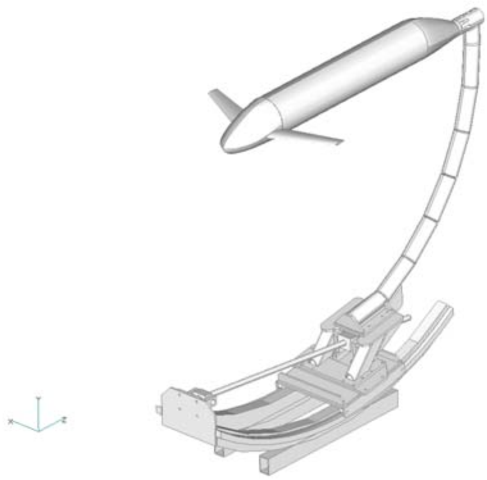


Fig.13 – Wind tunnel manipulator – initial state

Fig.14 – Wind tunnel manipulator – final state

model is shown in the fig.12, the list of natural frequencies is in the tab.3. It is obvious from the tab.3, that the initial attachment was not stiff enough and adaptation of the attachment to increase the stiffness was necessary.

Objectives of the following optimization study were: All natural frequencies of the attachment (with model installed) above 20 Hz and minimum influence impact of the attachment to the wind flow section. A several attachment configurations were analyzed, the final one is shown in the fig.14, list of natural frequencies is presented in the tab.4.

Tab.4 – Wind tunnel manipulator – final state – natural frequencies

#	f [Hz]	description
1	26.4	Attachment vertical bending 1
2	36.8	Attachment horizontal bending 1
3	48.3	Attachment horizontal bending 2
4	61.9	Attachment vertical bending 2
5	98.9	Attachment space bending

Further complication represented usage of the VZLU strain gauge balance (fig.13), which was (from the principle) flexible and affected as a hinge. It was practically impossible to reach enough stiffness of attachment with balance. Therefore the balance must have been used just only for the static tests and attachment configuration for the dynamic tests was with no balance. Natural frequencies of attachment / balance / X-DIA Component Model system are listed in the tab.5.

Tab.5 – Wind tunnel manipulator (initial) / balance / model natural frequencies

#	f [Hz]	description
1	6.9	Balance vertical bending
2	7.5	Balance horizontal bending
3	15.9	1^{st} attachment vertical bending
4	16.8	1^{st} attachment horizontal bending

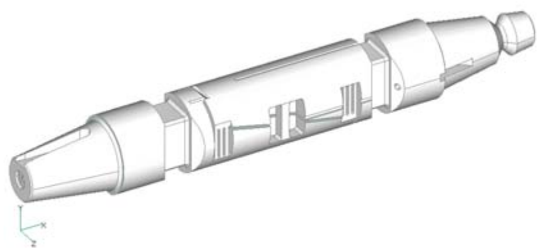


Fig.15 – VZLU strain gauge balance

5. Conclusion

The X-DIA Component Model aeroelastic tests preparation phase was finished successfully and the model is prepared for testing. The model wind tunnel installations for the static and dynamic tests are shown in the fig.16ab.

6. Acknowledgements

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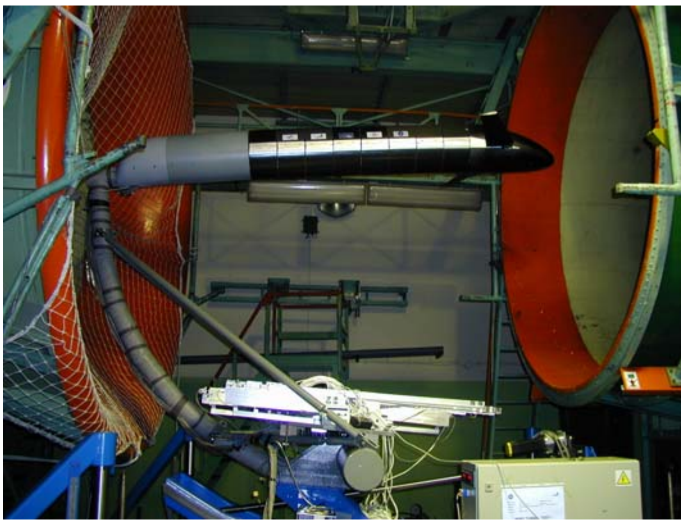

Fig.16a – X-DIA Component Model static test configuration

Fig.16b – X-DIA Component Model dynamic test configuration

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