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Determination of Aerodynamic Coefficients and Visualization of the Flow Around the LASTA-95 Aircraft Model
Part I: Experimemtal Method

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A test of the flow field around the *LASTA*-95 aircraft model was performed in the subsonic wind tunnel of the Military Technical Institute *(VTI)*, for the speed of undisturbed flow which corresponds to the Mach number M = 0.1. Aerodynamic forces and moments were measured by a six-component internal strain gage balance. Tufts were used for flow visualization in the boundary layer.

The goal of the experiment was to make comparison of the aerodynamic coefficients and the flow pattern obtained by the experiment and by the simulations of the flow possible i.e. to provide reliable experimental data for the purpose of uncertainty analysis of the numerical results. Fluent 6.1 was used for simulation of the flow.

In this paper, the testing results of the *LASTA*-95 model in the T-35 wind tunnel, at Mach number M = 0.1 are shown. The results obtained by the experiment are to be used later for comparison with the results obtained by the Computational Fluid Dynamics (CFD) simulations of the flow.

Key words: **aerodynamic testing, flow visualization, aerodynamic coefficients, flow pattern, boundary layer, trainer aircraft.**

Labels

Cx – drag coefficient
y – side force coefficient
Cz – lift coefficient
Cl – rolling moment coefficient
Cm – pitching moment coefficient
Cn – yawing moment coefficient
L – model length, [m]
lsat – model referent length, [m]
Sre – model referent area, [m^2]
M – Mach number
pst – static pressure, [bar]
p0 – total pressure, [bar]
q – dynamic pressure, [bar]
Re – Reynolds number
T0 – total temperature, [K]
V – Velocity, m/s
δZ – Deflection angle of flaps, [°]
δH – Deflection angle of elevator, [°]
δV – Deflection angle of rudder, [°]
δl/δr – Deflection angle of left/right ailerons, [%]
RSN – Run Sequence Number
Xr – distance between the point of reduction and the front of the model, [m]
Xref – distance between the point of reduction and the virtual center of balance, [m]
C.B. – Center of the internal six-component balance
R.P. – Reference Point
F.S. – Transducer full scale
ABLE 2" MK XVIII – Internal six-component 2" balance by the ABLE Corporation
MSS – Model Support System
TEM – External six-component balance/model support N^o 348
VTI – Military Technical Institute
NACA – National Advisory Committee for Aeronautics
CFD – Computational Fluid Dynamics

Introduction

A modern process of aircraft and missile design requires the use of a variety of theoretical, experimental and numerical methods. The experiment means measuring the aerodynamic forces and moments on the model in the wind tunnel and visualization of the flow around the model.

The Computational Fluid Dynamics (CFD) simulations play an important role in eliminating preliminary models at the beginning of the design process and leaving expensive wind tunnel testing for detailed models that are close to the final design.

In article [7], the CFD results are compared to the wind tunnel ones, for incidence that is related to a moderately steep spin. Besides the aerodynamic coefficients, the velocity field over the vertical stabilizer and rudder is also compared for two configurations, with and without the horizontal tail.

Fluent 6.1 was used for simulations of the turbulent flow around the LASTA-95 aircraft model. The solver of the software is based on the finite volume method for discrete governing equations of the flow.

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The experiment was performed in the test section with the rear model support system of the T-35 subsonic wind tunnel.

The experiment included the testing of the LASTA-95 model at M =0.1, with and without the horizontal tail, for the range of high angles of attack $22^\circ < \alpha < 52^\circ$, and with the sideslip angles of $\beta = 0^\circ$ and $\beta = -10^\circ$, respectively. The deflection of the control surfaces is defined in the test programme.

The results for the aerodynamic coefficients and the flow pattern in the boundary layer around the LASTA-95 model, are shown in this paper. Measuring of the aerodynamic forces and the moments on the six-component internal strain gage balance ABLE 2" MK XVIII and visualization of the flow with tufts were performed in the T-35 wind tunnel in the VTI, for the speed of undisturbed flow at Mach number $M = 0.1$ and the angles of attack in the range from $22<\alpha<52^\circ$.

Along with the LASTA-95 model, the testing results, the results of the simulations of the airflow, the wind tunnel T-35, the instrumentation, the methods of data acquisition and reduction as well as the results obtained by flow visualization with tufts, and the course of the experiment, are described. In this article, the testing results are shown in the form of figures and diagrams.

Experiment

Wind tunnel

The determination of the aerodynamic coefficients and the visualization of the flow were performed in the T–35 subsonic wind tunnel in the VTI.

The wind tunnel is of a continual type. The test section has the octagonal cross-section, with 4.4 m in width, and 3.23 m in height. The test section cross-section area is 11.93 m^2. The length of the test section is 5.5 m.

Testing of the LASTA-95 model was performed for the speed of undisturbed flow which corresponds to the Mach number $M = 0.1$. The aerodynamic forces and moments were measured on the six-component internal strain gage balance. Tufts were used for flow visualization in the boundary layer.

Test programme

The summary of the test programme for the LASTA-95 model is given in Table 1.

Tabele 1.

RSN	Configuration	α [˚]	β [˚]	δ_Z [˚]	δ_l/δ_r [%]	δ_H [˚]	δ_V [˚]	Landing gear
204	W-F-VT-HT	$22 < \alpha <52$	0	0	0/0	0	0	-
219	W-F-VT-HT	$22 < \alpha <52$	-10	0	0/0	0	0	-
245	W-F-VT	$22 < \alpha <52$	0	0	0/0	-	0	-
248	*W-F-VT*	$22 < \alpha <52$	-10	0	0/0	-	0	-

W - wing, F- fuselage, VT- vertical tail, HT- horizontal tail

Model

The VTI designed a family of the LASTA airplane models for the purpose of wind tunnel testing. The wing span of the LASTA-95 model is 1.803m. This model has an extremely high accuracy of manufacture; maximum error is 0.03 mm.

The LASTA-95 model (Figures 1 and 2) has internal space of adequate size for setting up a six-component wind tunnel balance ABLE 2" MK XVIII, with 50.8 mm in diameter. The geometric characteristics of the model are shown in Table 2 and in Fig.3. The airfoils in the root and on tip of the wing are NACA 63_2415. The airfoils of the horizontal and vertical tails are symmetrical. The airfoils in the root of the horizontal and vertical tails are NACA 64_A012. The airfoils on tip of the horizontal and vertical tails are NACA 64_A008. The angle between the leading edge of the swept wing and the fuselage axis is 2.82º, aspect ratio of the wing is 6.3, and its installation angle is 2º in relation to the fuselage axis. The angles between the leading edge of the horizontal and the vertical tail, and the fuselage axis are 11.07º and 53.0º, respectively. The wing has a dihedral angle of 4º and it is non-linearity geometry warped with -3.5º.

Table 2. The basic geometric characteristics of the LASTA-95 model

LASTA model	Wing area [m^2]	Wing span [m]	l_{sat} [m]	Fuselage length [m]	X_r [m]	X_{ref} [m]
95	0.516	1.803	0.2922	1.581	0.4946	0.1482

Figure 1. The LASTA-95 model on the model support system in the T-35 wind tunnel test section (rear view)

Figure 2. The LASTA-95 model on the model support system in the T-35 wind tunnel test section (front view)

The LASTA-95 model is scaled 1:5. The main part is fuselage made of iron grid. The fuselage is designed for the installation on the internal six-component wind tunnel balance with strictly defined geometry. The model wing is made of duralumin.

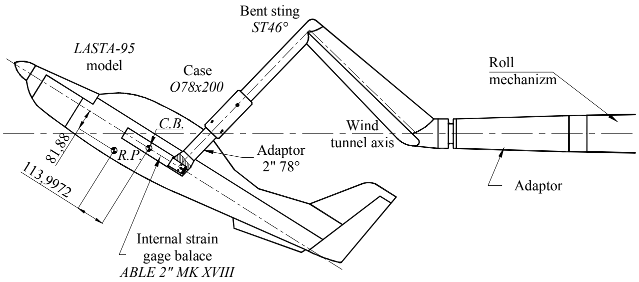

Figure 3. Sketch of the LASTA-95 model mounting at the model support system

Instrumentation, data acquisition and data reduction

The experimental data acquisition system in the T–35 consisted of 64 – channel Neff 620/600 system controlled by the VAX 8250 computer. The 16-bit A/D converter digitalizes data from all analogous channels. The approximate accuracy of the A/D conversion is 0.1 PS of channels. The sampling rate for all the channels was 200 samples per second. Digital data were received by the *Digital ALFA SERVER* and written on a disc for further processing.

Data processing was performed after each testing sequence by the standard software T35–APS that is in use for data processing measurement in all VTI wind tunnels. The processing was performed in following phases:

- reading of the written raw data, normalization and conversion into the standard format,
- determination of the flow parameters,
- determination of the position of the model and
- determination of the aerodynamic coefficients.

The measuring of the stagnation pressure P_0 and the stagnation temperature T_0 in the upper part of the collector and the static pressure P_{st} at the exit of collector of the wind tunnel were necessary for the determination of the values of the Mach and Reynolds numbers in the wind tunnel test section. Equations of the isentropic, incompressible fluid flow were used for determining the parameters of the undisturbed flow in the test section [6].

Two coordinate systems were used during data processing: wind tunnel and aerodynamic coordinate system. The wind tunnel, the balance and the relative coordinate systems were used only in computing intermediate results [6].

Visualization of the flow in the boundary layer

Basic fluids used in experimental aerodynamics, around airplanes and their models, cannot be observed or recorded, because the mentioned fluids are colorless. Flow visualization methods can transform an unvisible picture of the flow field into a visible one [1-6].

Altough visualization methods can be divided according to different criteria, only five groups of methods will be mentioned here:

- flow visualization by tufts,
- flow visualization by indicators (markers),
- flow visualization by coatings,
- special methods of flow visualization and
- optical methods of flow visualization.

The flow visualization by tufts is very often used for flow field investigation in the wind tunnel test section and in the complete area of the test section. The method is freqeuntly used for subsonic flow, but very effective results can be obtained for supersonic flow [2]. Using this method for rotational flow is of special importance. This method is also used in free flight airplane tests [2].

Tufts are glued onto the model surface or on a special grid, which is positioned in front or behind a model [5]. Bending of tufts is observed or recorded, since it is supposed that they are thin enough, without innertion, and able to follow all changes of the local velocity vector. During selection of tuft characteristics, technique of their glueing and spreading on the model surface, one must have in mind to bring minimum disturbance into the flow, in order to obtain the most authentic record possible.

Experimental results

The efects of flow visualization around the LASTA-95 model at Mach number M = 0.1 in the T-35 wind tunnel are shown in Figures 4 and 5.

The basic flow parameters for both testing of the LASTA-95 model are shown in Table 3.

Figures 4 and 5 show the effects of the flow visualization around the model at the angle of attack α = 44.48^o and the sideslip angle β = 0^o, for a configuration of the model with and without the horizontal tail, respectively.

Figure 4. Flow visualization around the LASTA-95 model at M = 0.1, the angle of attack α = 44.48^o and the sideslip angle β = 0° [6]

Figure 5. Flow visualization around the LASTA-95 model at M = 0.1, the angle of attack α =44.64° and the sideslip angle β = 0° [6]

The efects of flow visualizaton are very good. At a lower angle of attack, tufts are still and follow the flow direction.

An increased angle of attack causes changes in the boundary layer, and tufts follow these changes during the test. Changes in the boundary layer first start at the root part of the wing. The changes of the boundary layer spread in the direction of the wing end. These effects cause a drop of lift force and an increase of drag force.

Table 3. The basic flow parameters [6]

RSN	M	p_0 [bar]	p_{st} [bar]	MR$_e$	T_0 [K]	q [bar]	V [m/s]
204	0.109	0.994	0.986	0.68	301.6	0.008	37.824
219	0.099	0.994	0.988	0.62	301.3	0.007	34.502
245	0.1	0.994	0.987	0.64	296.8	0.007	34.501
248	0.104	0.988	0.981	0.67	294.7	0.007	35.751

The experimental results of testing the LASTA-95 model at Mach number $M = 0.1$ in the T-35 wind tunnel are shown in the diagrams (Figures 6, 7, 8 and 9) [6].

Fig.6 shows the diagrams of the drag coefficient, the lift coefficient and the pitching moment coefficient, for the configuration of the LASTA-95 model with the horizontal tail, which are obtained in the testing at $M = 0.1$, at the angle of attack $\alpha = 22^o$ to 52^o, and the model sideslip angle of $\beta = 0^o$.

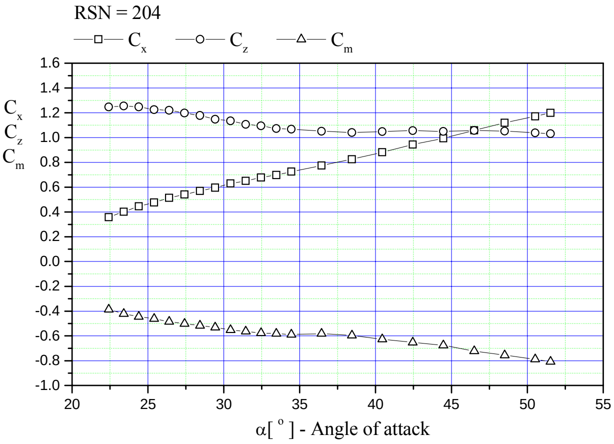

Figure 6. Diagrams C_x, C_z and C_m versus the angle of attack α[°], RSN=204

Fig.7 shows the diagrams of the drag coefficient, the lift coefficient and the pitching moment coefficient, for the configuration of the LASTA-95 model with the horizontal tail, which are obtained in the testing at $M = 0.1$, at the angle of attack $\alpha = 22^o$ to 52^o, and the model sideslip angle of $\beta = -10^o$.

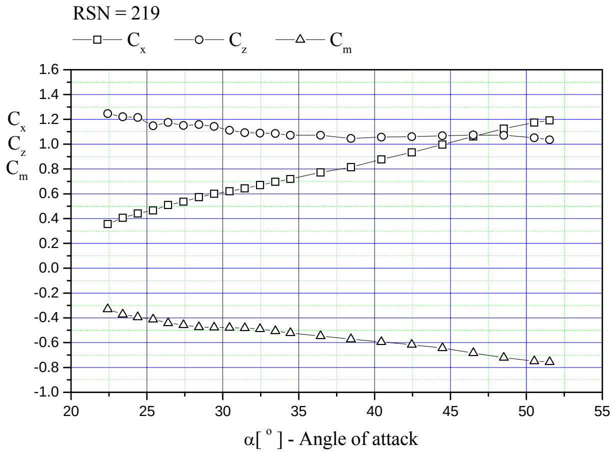

Figure 7. Diagrams C_x, C_z and C_m versus the angle of attack α[°], RSN=219

Fig.8 shows the diagrams of the drag coefficient, the lift coefficient and the pitching moment coefficient, for the configuration of the LASTA-95 model without the horizontal tail, which are obtained in the testing at $M = 0.1$, at the angle of attack $\alpha = 22^o$ to 52^o, and the model sideslip angle of $\beta = 0^o$.

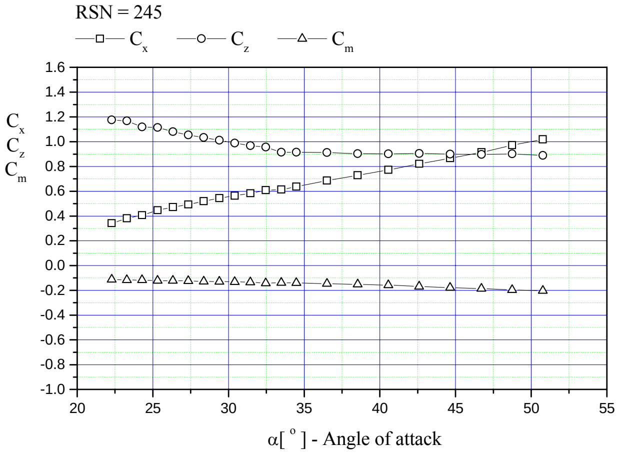

Figure 8. Diagrams C_x, C_z and C_m versus the angle of attack α[°], RSN=245

Fig.9 shows the diagrams of the drag coefficient, the lift coefficient and the pitching moment coefficient, for the configuration of the LASTA-95 model without the horizontal tail, which are obtained in the testing at $M = 0.1$, at the angle of attack $\alpha = 22^o$ to 52^o, and the model sideslip angle of $\beta = 0^o$.

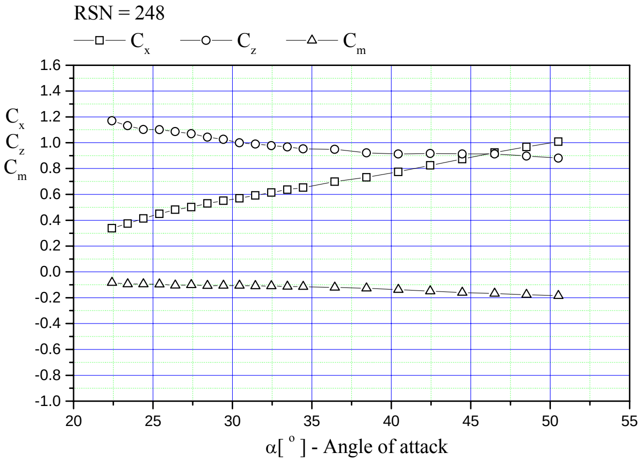

Figure 9. Diagrams C_x, C_z and C_m versus the angle of attack α[°], RSN=248

Conclusions

The basic flow parameters, Mach number and pressure, are within the accuracy limits of the measuring devices and equipment, which is the same for all tests. It should be mentioned that the obtained values of the aerodynamic coefficients are expected. The results of the LASTA-95 model test in the T-35 wind tunnel can be used for further analyses and they will be of great benefit in future tests.

Visualization with tufts gives a very good, clear and expected presentation of the flow around the LASTA-95 model. The effects of the visualization test with tufts are clearly visible. To get a clear picture of the flow around a model, the flow visualization method by tufts in the boundary layer was a very good choice.

The obtained flow visualization results can be completely accepted and the stated conclusions used for further activities.

In this paper (Part I of a two-point series), a complete experimental determination of the aerodynamic coefficients of the model was presented. Also, flow visualization around the model was presented. Computational Fluid Dynamics (CFD) has already demonstrated its capability to produce solutions of various, sometimes very complex flows of practical interest. Nowadays, the question is not so much whether a simulation of this flow can be made, but rather if the solution is reliable enough for the use in design practice? The development of methods for the uncertainty analysis of numerical results of flow simulation is not possible without the comparison of numerical and reliable experimental results.

The results of this experiment are evidence that it is necessary to use more methods of investigation to get more reliable results.

The simulations of the flow were performed in the Fluent 6.1. The flow patterns on the model were numerically simulated for the angle of attack $\alpha = 44.48°$ for both configurations [7].

A comparative review of the experimental aerodynamic coefficient values and the photos of the flow patterns, obtained in the T-35 and the results of the numerical simulations of the flow, are given in article [7].

Table 4.

Configuration & flow conditions	C_x		C_z	
	experimental	numerical	experimental	numerical
W-F-HT-VT $\beta = 0^{o}$, V= 38 m/s	0.9941	1.0131	1.05	1.06
W-F-HT-VT $\beta = -10^{o}$, V= 35 m/s	0.9723	1.0257	1.01	1.08
W-F-VT $\beta = 0^{o}$, V= 35 m/s	0.8665	0.8961	0.90	0.94
W-F-VT $\beta = -10^{o}$, V= 35 m/s	0.8736	0.8880	0.91	0.94

The comparative results corresponding to the aerodynamic coefficients are given in Table 4 [7].

The aerodynamic coefficient values and the numerical flow pattern, obtained by simulation, show good agreement with the experimental results [7].

The good agreement of the numerical and experimental results shows a good quality of the complete process of determination of aerodynamic coefficients.

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Određivanje aerodinamičkih koeficijenata vizualizacija strujanja oko modela aviona LASTA-95

Deo I: eksperimentalni metod

Ispitivanje strujnog polja oko modela aviona LASTA-95 sa i bez horizontalnih površina je izvršeno u podzvučnom aerotunelu T-35, u laboratorijama VTI-a, za brzinu neporemećene struje sa Mahovim brojem M = 0,1. Merenje aerodinamičkih sila i momenata je vršeno unutrašnjom aerovagom. Vizualizacija strujanja u graničnom sloju je realizovana pomoću končića.

Cilj eksperimenta bio je da se omogući poređenje aerodinamičkih koeficijenata i strujne slike dobijenih eksperimentom i numeričkim simulacijama strujanja, to jest da se obezbede pouzdani eksperimentalni podaci za potrebe analize tačnosti rezultata proračuna. Numerička simulacija strujanja je izvedena u programu Fluent 6.1. U ovom radu su prikazani rezultati ispitivanja modela LASTA-95 u aerotunelu T-35 na Mahovom broju M = 0,1. Rezultati dobijeni eksperimentom iskorišćeni su kasnije za poređenje sa rezultatima dobijenim Computational Fluid Dynamics (CFD) simulacijom strujanja.

Ključne reči: **aerodinamičko ispitivanje, vizualizacija strujanja, aerodinamički koeficijenti, strujna slika, granični sloj, školski avion.**

Определение аэродинамических коэффициентов и визуализация потока около модели самолета Ласточка-95 Часть 1: экспериментальный метод

Исследование поля потока около модели самолета «Ласточка-95» со и без горизонтальных оперений проведено в дозвуковой аэродинамической трубе Т-35, в лабораториях ВТИ для скорости ненарушенного потока с числом Маха М=0,1. Измерение аэродинамических сил и моментов проведено при помощи внутренних аэровесов. Визуализация потока в пограничном слое реализованна при помощи ниток.

Цель этого эксперимента была воспрепятствовать сравнивание аэродинамических коэффициентов и картины потока, полученых путем эксперимента и численных моделирований потока, т.е. обеспечить достоверные экспериментальные данные нужные для анализа точности результатов расчета. Численное моделирование потока проведено в программе Fluent 6.1. В настоящей работе показаны результаты исследования модели самолета «Ласточка-95» в аэродинамической трубе Т-35 на числе Маха М=0,1. Результаты полученые путем эксперимента, позже использованы для сравнения с результатами полученными Computational Fluid Dynamics (CFD) моделированием потока.

Ключевые слова: **модель самолета Ласточка-95, визуализация потока, аэродинамические коэффициенты, картина потока, пограничный слой.**

Détermination des coefficients aérodynamiques et visualisation du courant autour du modèle de l'avion Lasta-95 Première partie: méthode expérimentale

L'examen du champ de courant autour du modèle de l'avion LASTA-95 avec ou sans surfaces horizontales a été fait dans la soufflerie subsonique des laboratoires de VTI et pour la vitesse du courant non perturbé à Mach M=0,1. Le mesurage des forces aérodynamiques et du moment est effectué à l'aide d'une balance aérienne intérieure. La visualisation du courant dans la couche limite a été réalisée au moyen d'un fil. Le but de cet essai était de permettre la comparaison entre les coefficients aérodynamiques et les images du courant obtenues par les examens et les simulations numériques du courant, c'est-à-dire d'obtenir les données expérimentales sures pour les besoins de l'analyse de la précision des résultats du calcul. La simulation numérique a été réalisée par le programme Fluent 6.1. Ce papier présente les résultats des essais sur le modèle LASTA-95 dans la soufflerie aérodynamique T-35 à Mach M=0,1. Les résultats expérimentaux ont été utilisés plus tard pour les comparaisons avec les résultats obtenus par la simulation du courant au moyen de Computational Fluid Dynamic (CFD).

Mots clés: **modèle d'avion LASTA-95, visualisation du courant, coefficients aérodynamiques, modèle du courant, couche limite.**