Universal Journal of Aerodynamics **3 (2015), 34-40**
www.papersciences.com

Wing with Soft Skin: The Effectiveness and Assessment

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Abstract

It is shown by this paper, that wing aerodynamic analysis has been completed, which has a soft and rigid part with different width. To determine the optimal width of the soft parts of the wing, as well as evaluation of its effect, the experiment has been carried out in a wind tunnel. The purpose of this research is to increase operating capacity of aircrafts, that is confirmed by the fact development of experimental aircraft with the soft wings. Potential soft surface attracted the attention of leading aviation specialists for the realization of the specific qualities projected aircraft. Experimental results can be used for designing folding portable aircrafts and for optimizing weight and aerodynamic performance.

Keywords

Wing with a Soft Surface, Aerodynamics Characteristics, Deformable Wing, Inflatable Wing, Soft Wing, Hybrid Wing.

1. Introduction

The purpose of this research is to increase operating capacity of aircrafts, which is confirmed by the fact development of experimental aircraft with the soft wings as shown in the Fig. 1. Potential soft surface attracted the attention of leading aviation specialists for the realization of the specific qualities projected aircraft [1], [2], [3].

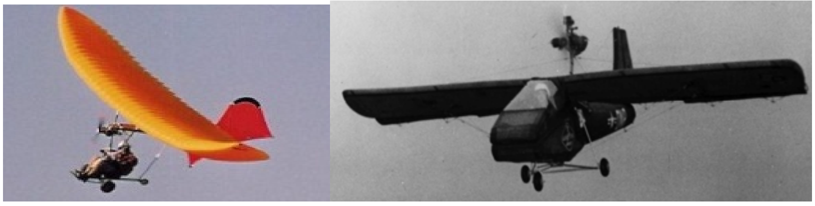


Fig. 1 Aircraft with inflatable wings

Scientific novelty:

- The concept of a wing with combine of a rigid front part and a soft inflatable trailing part.
- For the first time parametric computational and experimental studies have been done for the influence of parameters for proposed hybrid wing on its aerodynamic characteristics.
- For the first time for new aeroelastic wing with rigid front section, investigated the effect of the maximum load-bearing properties of the hybrid wing characteristics of its stability and controllability.
- For the first time, aerodynamic characteristics found experimantally for hybrid wings.
- Improved well-known method for solving the Navier-Stokes equations in terms of defining a new class of boundary conditions which is needed for creating a new type of computational models.

The goals and objectives:

The main goal of the research is to develop a common methodology aerodynamic design of the aircraft with a soft deformable wing. To do this, you must solve the following problem:

- Aerodynamic analysis and synthesis of the aircraft wing with soft surfaces. Analysis of the aerodynamic features of the aircraft with a soft deforming wing. Selection and justification of the study parameters layout, the limits of applicability of forming the applicability criteria of design solutions of the aircraft with a soft deforming wing.

- Development of algorithmic evaluation of the aerodynamic characteristics of the aircraft with a soft deforming wing that takes into account the influence of the deformable wing using numerical methods. Selection and justification of the methods with using computational aerodynamics. Planning computational experiment, the development of computational models. Analysis and generalization of the results.
- Assessment of changes in the aerodynamic characteristics of the aircraft with a soft deformable wing in a full-scale experiment on the flying model. Selection and justification of the prototype aircraft. Design and production of experimental flying model. Definition of instrumentation, methods of conducting flight tests and analyzing the results of the experiment.
- Development of a common algorithm formation of aerodynamic configuration of the aircraft with a soft deformable wing based on the results of computational and physical experiment.

2. Material and Methods

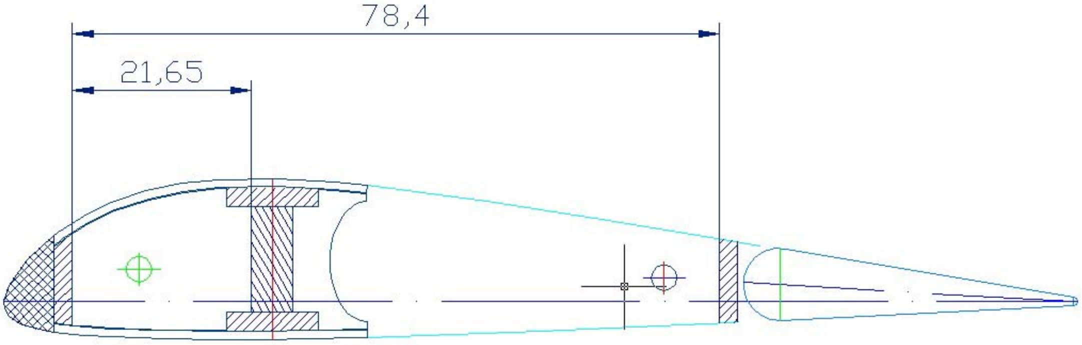
Experimental models:

For the experiment, four wing models with nonsymmetrical profiles are built [5]. Materials of models are balsa, plywood and windproof (parachute) cloth. plastic tube air intakes are mounted to inflate the soft part of the wing. Each model has a different ratio of the rigid part and the soft part of the overall wing chord b, namely:

- The first model: completely rigid;
- The second model: the rigid part - 70% b, soft part - 30% b;
- The third model: the rigid part - 50% b, soft part - 50% b;
- The fourth model: the rigid part - 30% b, soft part - 70% b;

Conceptual diagram of the experimental model is presented in Fig. 2.

Rigid wing:



Hybrid wing:

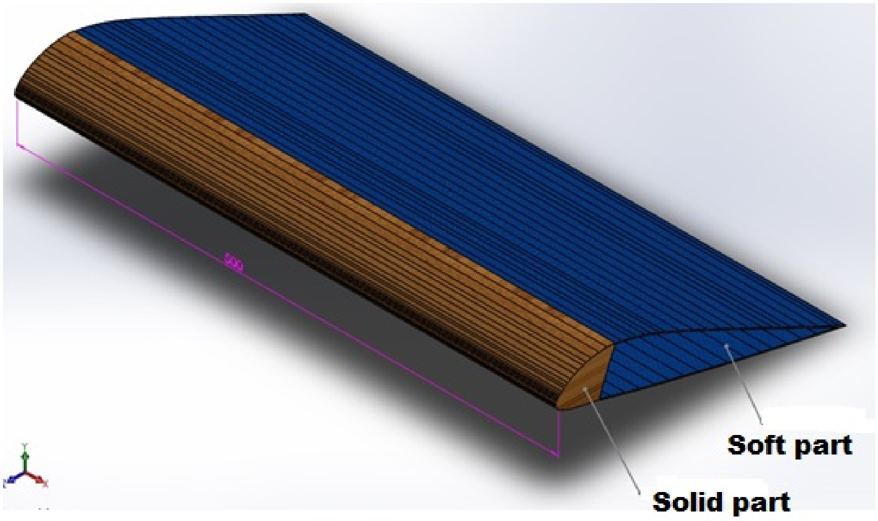


Fig. 2 Structural diagram of the experimental wing model

Experimental samples are shown in Fig. 3.

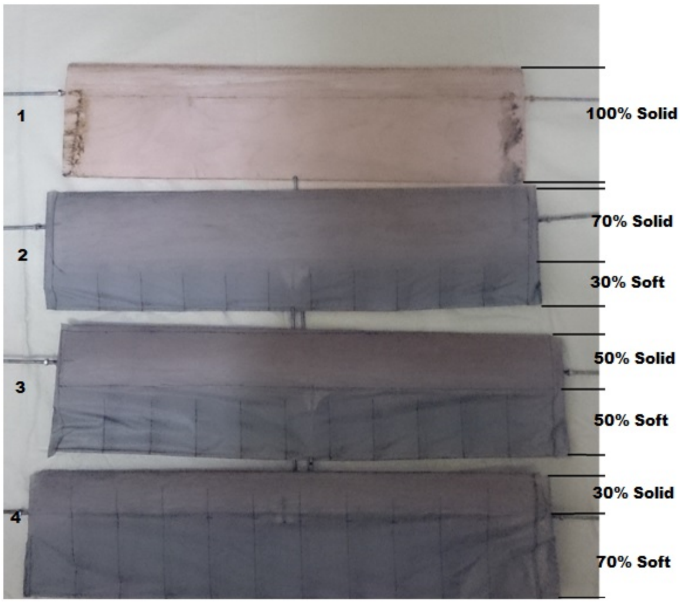


Fig. 3 Experimental hybrid wing models

The experimental setup:
UTAD-2 is an atmospheric low speed wind tunnel of closed-return type with an open elliptical test section. It is used for educational purposes in aerodynamics and flight dynamics as well as for scientific investigations, and commercial purposes such as certification of wind velocity and wind direction meters.

Fig. 4 General View of Test Section of UTAD-2 Wind Tunnel

Test section of UTAD-2 (Fig. 4) wind tunnel is of open type, elliptical cross section 750 mm wide, 420 mm high, and 900 mm long. Testing conditions correspond to those in tunnel hall: temperature 17...28 centigrade, atmospheric pressure 720...760 mm hg.

Free-stream velocity in the empty test section is continuously variable from 3.5 to 28 m/sec. Turbulence intensity is 2.4% [6].

For these experiments, model is mounted on external tree-component rider balance ABMK(t), which can work in manual balancing regime and as a strain gauge balance being a part of data acquisition and processing system.

UTAD-2 wind tunnel is equipped with external three-component rider balance ABMK(t), located above the test section. Lateral support base is constant and equal to 450 mm, longitudinal base can be continuously varied in 300...450 mm range. Balance provides measuring of three components P1, P2, and Q of full loading on the model in vertical plane and model weight compensation. Built-in mechanism for angle-of-attack alteration permits 60 deg variations with angle reading by dial. Drag, lift, and pitch moment coefficient dependences vs. angle-of-attack can be obtained in wind axes. Measuring range: P1 - 0...50 N, P2 - 0...50 N, Q - 0...50 N.

Both manual balancing and automatic data acquisition are possible. In the last case industrial strain gauge transducers ("Veda" company, Kiev) are connected to loading transfer path and remotely controlled electric drive is used for angle-of-attach change. Calibration is performed using special loading device and reference weights. Measuring errors are: 0.03 N for P1 and P2 components, and 0.014 N for Q component at 90% confidential probability.

Using the description above about the experimental wing models, aerodynamic experiments held in the laboratory of the Aerodynamics Department of National Aviation University of Ukraine. The purpose of this experiment is comparative evaluation of changes in aerodynamic characteristics: coefficients of lift C_y and drag C_x, maximum lift-drag ratio K, the critical angle of attack α, as well as the study of the bending deformation of the soft wings [4].

3. Experiment Results

Below, from Fig. 5 to Fig. 10, results of the wind tunnel experiment are shown.
Wing No: 1 – 100% rigid; Wing No: 2 – 70% rigid and 30% soft; Wing No: 3 – 50% rigid and 50% soft; Wing No: 4 – 30% rigid and 70% soft.

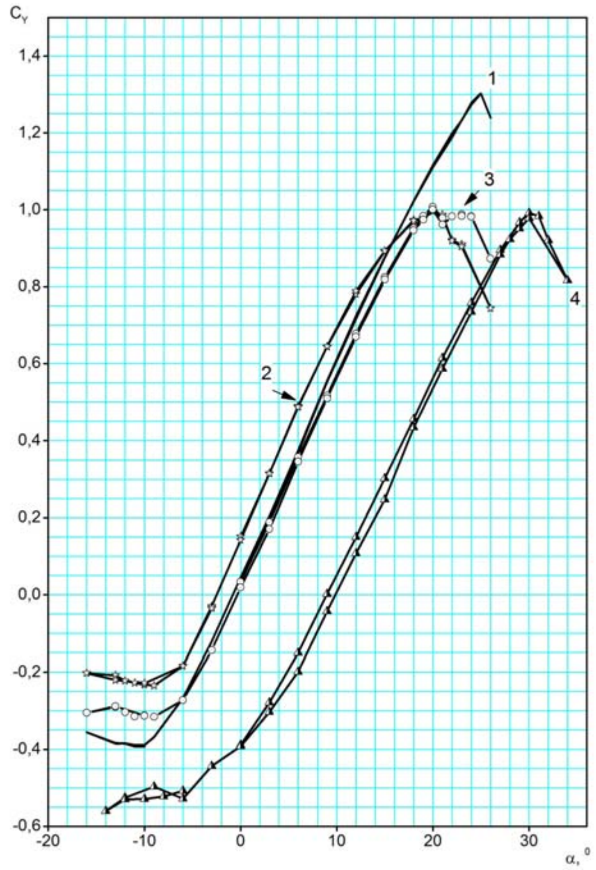


Fig. 5 The relation of $Cy=f(\alpha, X_{solid\ part})$. Re = 222603; M = 0,073;
Wing No: 1 – 100% rigid; Wing No: 2; 70% rigid and 30% soft; Wing No: 3 – 50% rigid and 50% soft; Wing No: 4 – 30% rigid and 70% soft.

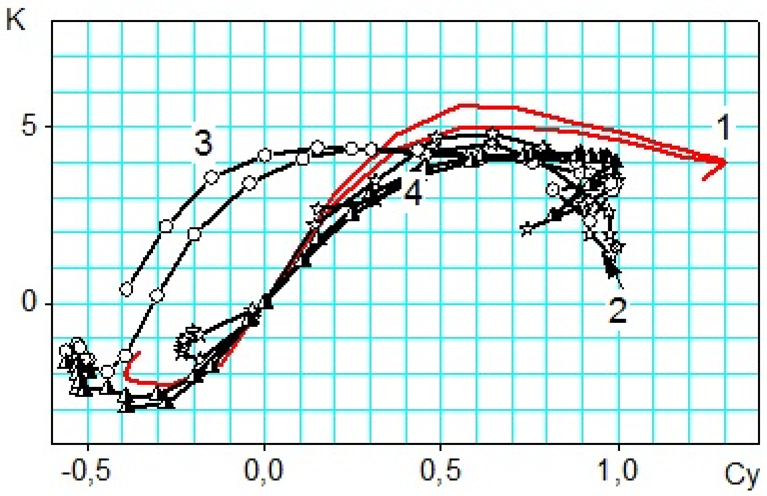


Fig. 6 The relation of $K=f(Cy, X_{\text{solid part}})$. $Re = 222603$; $M = 0,073$;
Wing No: 1 – 100% rigid; Wing No: 2; 70% rigid and 30% soft; Wing No: 3 – 50% rigid and 50% soft; Wing No: 4 – 30% rigid and 70% soft.

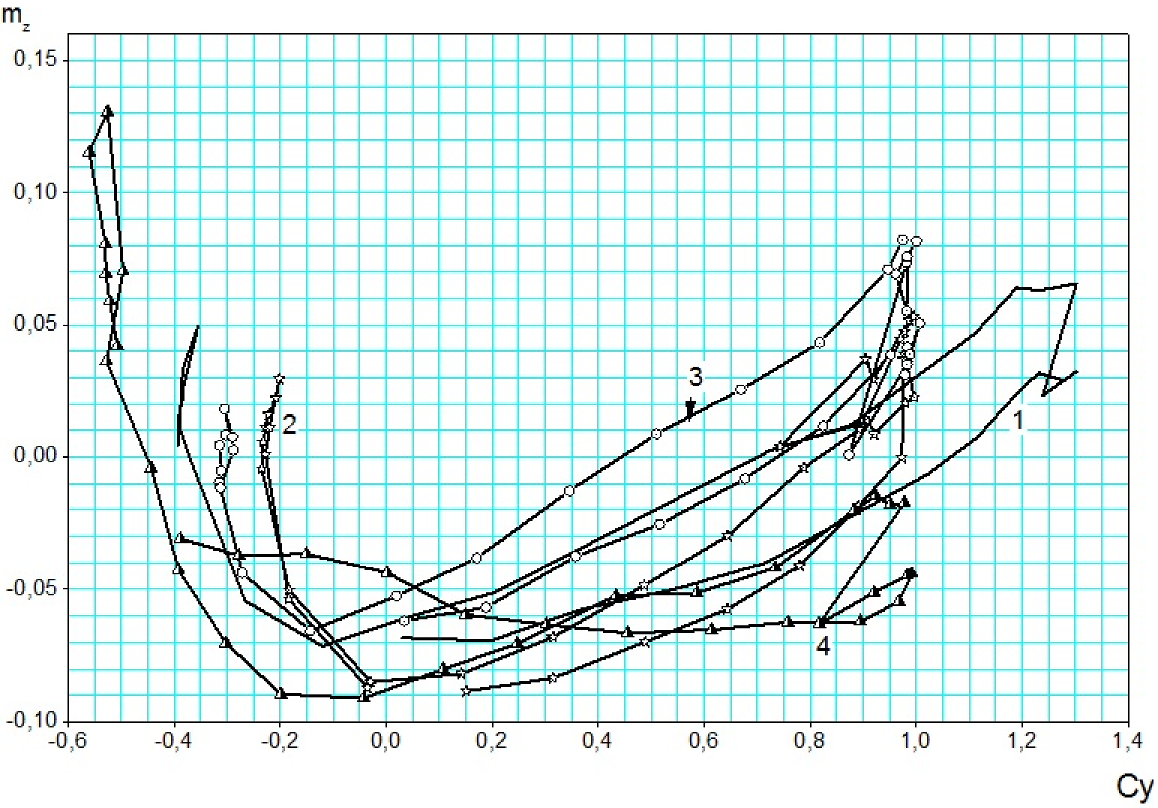


Fig. 7 The relation of $Mz=f(Cy, X_{\text{solid part}})$. $Re = 222603$; $M = 0,073$;
Wing No: 1 – 100% rigid; Wing No: 2; 70% rigid and 30% soft; Wing No: 3 – 50% rigid and 50% soft; Wing No: 4 – 30% rigid and 70% soft.

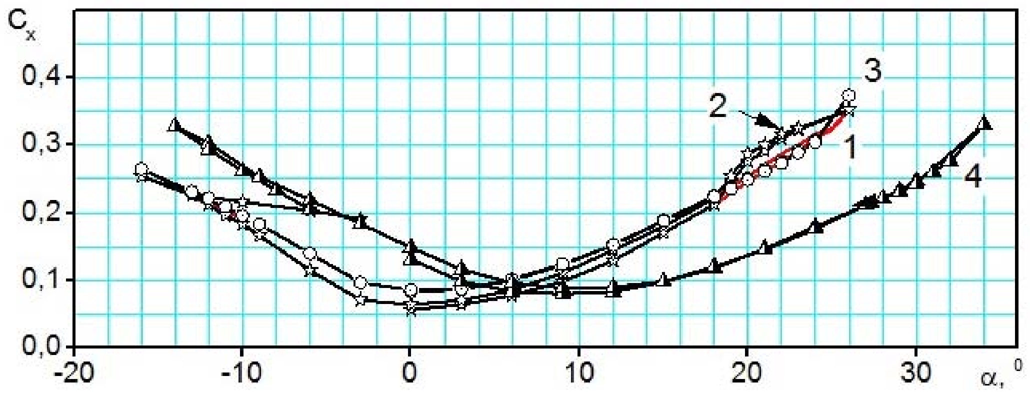


Fig. 8 The relation of $C_X=f(\alpha, X_{\text{solid part}})$. Re = 222603; M = 0,073;
Wing No: 1 – 100% rigid; Wing No: 2; 70% rigid and 30% soft; Wing No: 3 – 50% rigid and 50% soft; Wing No: 4 – 30% rigid and 70% soft.

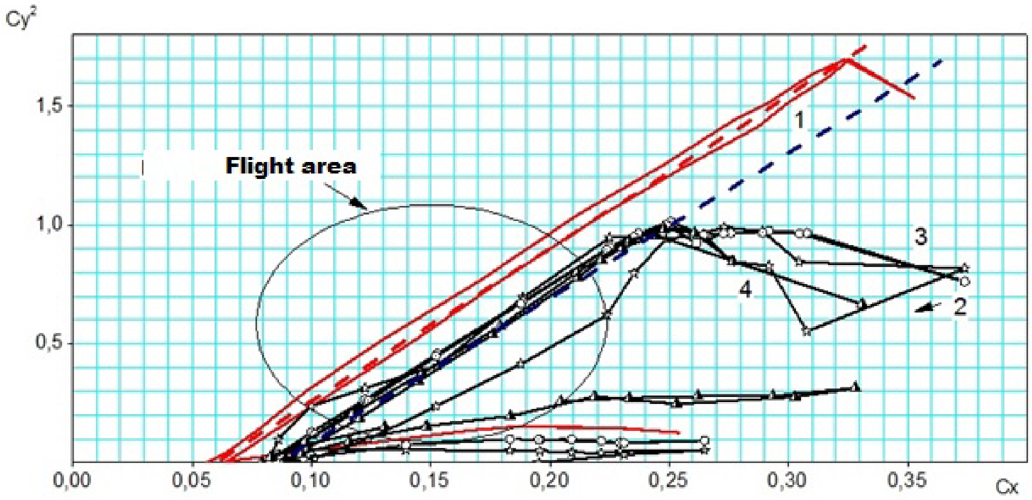


Fig. 9 The relation of $Cy2=f(Cx, X_{\text{solid part}})$. Re = 222603; M = 0,073;
Wing No: 1 – 100% rigid; Wing No: 2; 70% rigid and 30% soft; Wing No: 3 – 50% rigid and 50% soft; Wing No: 4 – 30% rigid and 70% soft.

Fig. 10 Wing No: 4 – 30% rigid and 70% soft. Angle of attack is α = 32º

Fig. 10 shows a photograph of the hybrid wing in process of experiment in wind tunnel for the study of aerodynamic characteristics.

4. Results and Discussion

Cy dependence on the angle of attack (Fig. 5). The maximum load-bearing properties in the soft part of the installation slightly reduced. The maximum lift coefficient of the rigid wing $C_{ymax} = 1.3$, and the maximum lift coefficient of the soft wing $C_{ymax} \approx 1$. But, by increasing the area of the soft inflatable part, the critical angle of attack is increased. From the experimental results for the wing no: 4, which consists of 30% rigid and 70% soft parts, the critical angle of attack reaches more than 30^o. The character of the flow separation is smoother, which has a positive effect on the parameters of the flight safety (Fig. 10). The value of the derivation of the C_y and α depending on the linear section corresponding to the unseparated flow for all versions of the wings is almost the same, indicating equal values of the wing extension effectiveness λ_{EF} for combination and for rigid wing.

Lift-drag ratio K dependence on C_y (Fig. 6)

Lift-drag ratio of hybrid wings 20% less than rigid wing. However it is observed that the hybrid wing lift-drag ratio value is less than the maximum, but it is more constant over a wide range of angles of attack. The maximum value of K in the flight range for the combined wing almost constantly, while at small values $C_y \approx 0.2 ... 0.5$ (that resp. Flight at high speeds) as an option combined wings becomes higher than that of a rigid wing, i.e. Soft inflatable wing at a certain ratio layout options may be more suitable for flying at high speeds.

The dependence of Mz on C_y (Fig. 7)

Application of the hybrid circuit does not cause a significant change in the torque characteristics in comparison with fixed-wing. Also, torque characteristics are reduced by increasing the area of soft inflatable parts. As the results presented in the form of the hysteresis loops for rigid and combined wings, for soft wing hysteresis value is not increased as compared with the rigid wing. So, there is no need for an additional balancing when establishing hybrid wings.

Dependence of C_y^2 Cx (Fig. 9)

Following from the dependence in soft wings like a rigid structure, there is the presence of a linear portion according to C_y^2. Depending C_y^2 (Cx) of the rigid wing and options combined wings almost equidistant, with the value for Δ Cx flight range is almost the same, and obviously determined by the design of the air intakes. This clearly demonstrates the influence of the inductance equal to the aerodynamic characteristics of the wing, which indicates the conservation carrier surface forms in the flight range of the C_y. Airfoil form of the aircraft remains constant.

5. Conclusions

Compared with a rigid wing, the appearance of the soft part causes a reduction in the maximum load-bearing properties and the critical angle of attack. Based on the movie of a scientific experiment, it is clear that the soft part of the wing is deformed at high angles of attack. This effect increases the damping characteristics of the wing, as well as reduces the likelihood of abrupt control flow separation from the wing. The damping effect is also significantly reduces the maximum realizable values of loads acting on the structure.

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