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MORPHING WING WITH SURFACE DISCONTINUITY - COMPARATIVE TESTS

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Abstract

This article describes comparative analysis of the novel morphing flying wing and reference (non-morphing) flying wing, both sharing the same geometry. The reason for this research is to create novel morphing wing which is not challenged by inevitable problems with elastic deformation of wing structure and can potentially provide better performance, stability and maneuverability in comparison to conventional tailless aircraft. This task is based on a comparative numerical analysis of morphing and non-morphing flying wings. This study is also intend to prepare the morphing wing for the flying phase and carry out comparative fly tests. The intermediate goals are to test and optimize the kinematic solution of the morphing wing and to develop a mulit-DOF control strategy for the system.

1 Introduction

Most of the aircraft built by people are characterized by a stiff airframe. However flying conditions (airspeed, altitude, etc.) change strongly during aircraft flight which causes that change of the configuration (geometry) is worthy to consider. Aircraft requires to be controled, which is usualy satisfied by specialised control surfaces (elevator, aileron, rudder) but generally it requires also the change of geometry. Many different ideas how to adapt the aircraft configuration to the current flight conditions were born and tested with variable luck [1]. The good solution is so-called morphing wing (or all geometry), which allows to fit the configuration to the current flight conditions [2]. Continous change of the aircraft skin during the change of geometry gives relatively small drag but causes many design problems (airframe, materials, etc.).

The proposed novel construction of the discontinuous morphing flying wing [3], despite relatively simple design, has not been previously used as wing structure in such configuration. It is formed by individual, rigid segments without shared or continuous skin. During flight, segments are pivoted around main spar, effectively changing nonlinear wing twist. It would be the only mechanism used to create desired spanwise lift and drag distribution for control and performance optimization. It is estimated that each semi span-wing will contain from 10 to 15 segments.

Fig. 1 Idea of discontinous morphing wing

Such wing structure may escape some definitions of morphing, because of its skin discontinuity. Indeed, its construction reassembles more

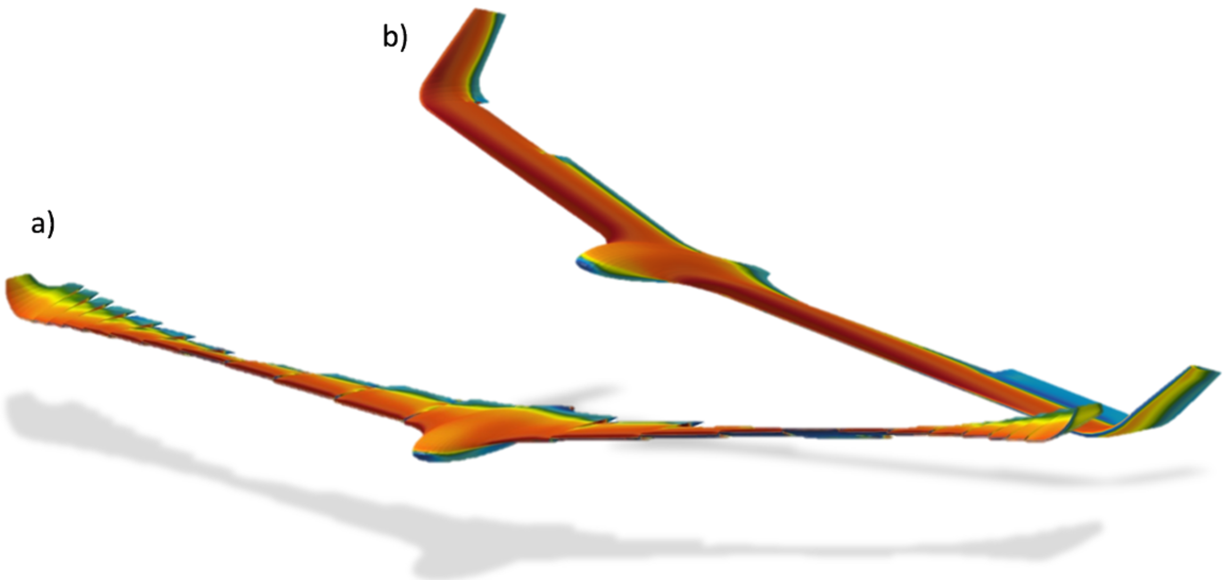

Fig. 2 Morphing (a) wing vs. Reference wing (b)

multi flap control system than continuous morphing wing concept. However, based on functionality, such structure meets the criteria of continuous morphing [4]. In fact, it integrates all control function (pitch, roll and yaw) with performance optimization in continuous fashion only by changing multipoint wing twist distribution. As it was mentioned before, continuously changing aircraft skin without any discontinuities will generate less drag during flight than its discontinuous counterpart but taking into account current state of material technology, advanced continuous morphing solutions are yet to come. It is worth noticing, that previously mentioned birds' wing, as an unmatched example of morphing, also lacks surface continuity (Fig. 1). It is rather composed of few dozens of flight feathers that are independent and quite rigid structures, which are only when pressed together, forms smooth wing surface. Although similar, presented solution doesn't work on the same principle as bird's wing, since it doesn't have to provide propulsion, but potentially can have desirable flight capabilities.

The reference flying wing - the result of the NORD project (Numerical Optimization Results Demonstrator) - is designed to achieve optimized geometry for aerodynamic performance and flight stability [5] (Fig.2b). This aircraft has classical, rigid composite structure and will be used as the initial configuration and reference point for comparative wind tunnel experiments with the developed morphing wing.

2 Structure

The novel morphing wing mechanism is based on variable nonlinear multipoint distribution of wing twist, as the only mechanism for flight control and performance optimization. Additionally, wing's variable wing sweep and dihedral capabilities are briefly described. Its kinematic solution utilizes morphing concept advantages without challenges of the structure elastic deformation. This is possible due to the wing's modular construction formed by the rigid, independent segments, pivoted around the main spar (Fig. 3). In contrast to conventional designs, the morphing wing does not have any dedicated control surface such as aileron or elevator, since all wing segments act as the all moving surface controls.

Segment's sliding-pivot mechanism delivers four degrees of freedom (DoF) to each segment. They are three rotational about all three axes, and one translational on main spar. Interestingly

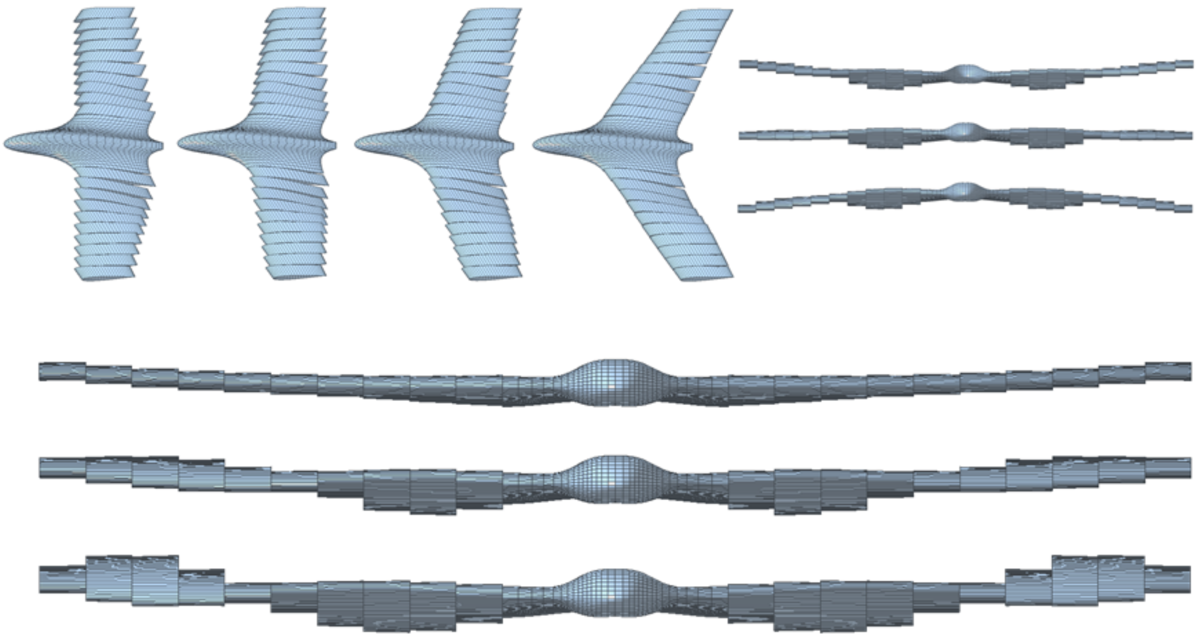

Fig. 3 Morphing possibilities

such mechanism allows for morphing (continuous change) of three wing's geometric parameters: two out of plane - Twist distribution and Dihedral angle and one planform - Sweep angle.

Variable Sweep is classified rather as variable geometry than morphing capability. It is worth to notice however, that in case of discontinuous morphing wing span is constant during change of sweep angle (Fig.3 - top,left), and it is in opposition to variable geometry, where span decreases with increase of sweep angle. Similar phenomena are true for variable dihedral (Fig.3 - top,right) and in both cases length of the main spar inside morphing part of the wing is varying during morphing - increasing wing spar bending (in vertical plane) and with angle of wing sweep. This is the reason for fourth DoF - segments have to slide on the main spar, while it is re- or extracted from the fuselage (un-morphed part of the aircraft).

In the current investigation stage, a semi-span is formed from 10 segments and has no winglets (Fig.2a) contrary to reference aircraft. In future research number of segments can be increased to the point where difference from smooth (continuous) bird's wing-like surface will be unnoticeable, in terms of both appearance and aerodynamic performance. The kinematics solution was considered in [3] (Fig.4).

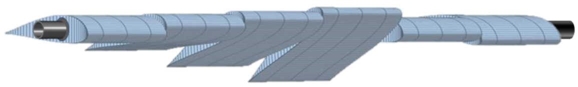

Fig. 4 Discontinuous morphing kinematics

3 Numerical computations

The project involves optimization of the morphing wing twist distribution in attempt to find the best configuration for realization of the control strategy and geometry adaptation to the different flight conditions. The results will allow for a completely new approach to morphing of aircraft structures, not limited by the problems associated with elastic deformation. By breaking the paradigm of wing surface continuity, there is possibility of new approach to aircraft design based on discontinuous morphing

3.1 Morphing wing without winglet

By design, the morphing wing stability in all axis is achieved by careful design and active morphing wing technology, mainly by nonlinear twist distribution. Reference aircraft without winglets will suffer an unflyable condition. The results of calculation show that longitudinally trimmed flight is not possible until -4.59 deg of AoA, where the lift force drops to 35% of aircraft weight. Reference aircraft has been designed by the use of numerical multi-disciplinary optimization (MDO) methodology [6][7][8], where all geometric properties are highly intertwined and cannot be separately removed without negative effects. To solve this problem search algorithm has been deployed to find new linear wing twist where lift force balances aircraft weight and simultaneously the aircraft is longitudinally trimmed.

As this morphing wing design is prepared for comparative analysis with reference aircraft, morphing wing flight performance should be at the comparable level with its reference. To achieve that, new wingtip airfoil with more reflexed camber line has been selected. It has more suited aerodynamic characteristic, mainly because pitching moment coefficient is closer to zero than in NORD aircraft.

The search algorithm revised longitudinally trimmed and balanced configuration with total twist 6.6 deg at -1.84 deg of AoA. This results from assumed constrains that both aircraft must have similar aerodynamic coefficients of lift and pitching moment together with static stability measure dCm/dCz. Unfortunately, drag coefficient increased significantly which indicates necessity for the search of better suited wingtip airfoil. Although, to continue with verification of developed methodology search of new airfoil has been postponed as it is not critical for testing. Comparison of local lift coefficient distribution for longitudinally trimmed and balanced investigated aircrafts, namely reference aircraft (NORD), NORD without winglets and final morphing wing MORDOW are presented in Fig.5.

3.2 Numerical process

Due to the vast number of possible geometric combinations of the morphing wing, a numerical search process was developed to find necessary configurations that meet required criteria and are promising candidates for wind tunnel testing. The search process is defined in Matlab environment, while all aerodynamic calculations are produced by external software package PANUKL [9][10] - based on low order 3D panel

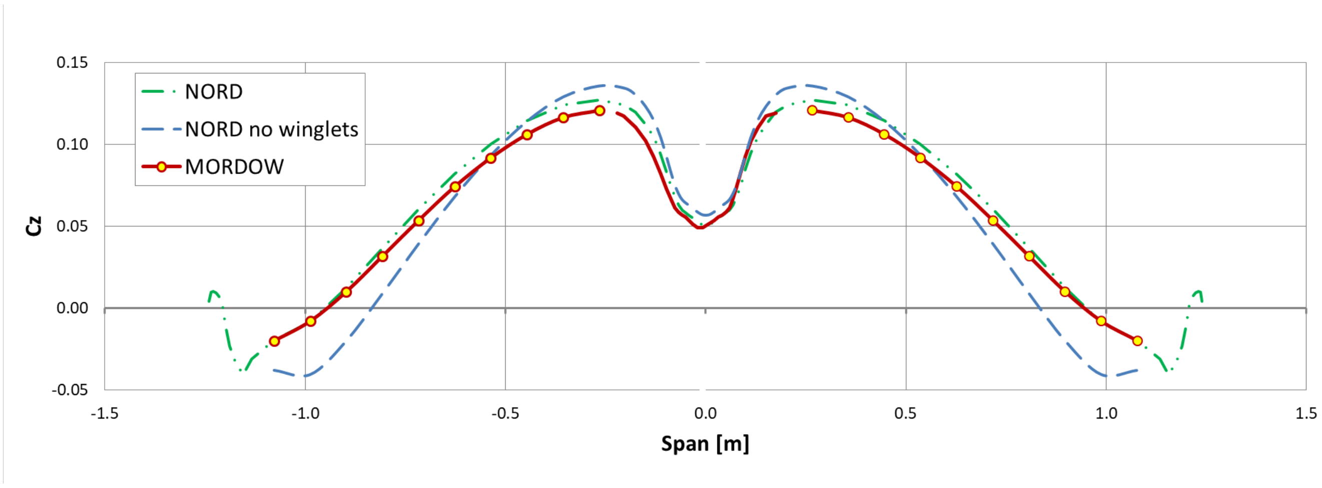

Fig. 5 Spanwise lift distribution

method (Fig.6). The use of this low-cost method is dictated on one hand by exponential number of possible configurations, and on the other because PANUKL can work in batch mode and therefore be easily controlled by Matlab routines.

To facilitate effective data flow and control over the process, tailored modular programming routines have been written in Matlab environment. These routines are built around PANUKL package which serves as the core of the aerodynamic analysis in the process. Chosen methodology provides possibility of independent computation of selected observations (different twist distribution). In other words different configuration of segments deflection can be computed simultaneously or in parallel. This feature can seriously accelerate total time for calculation of mathematical model when used on multi core computers. In described process, parallel instances of PANUKL software are started from within Matlab routines until all available processor/core resources are utilized. The software loop (Fig.7) is waiting for any instance of PANUKL to finish its calculations before executing calculation of new twist distribution by new instance of PANUKL until all configuration are calculated.

3.3 Aerodynamic results

Basing on computed simulation model of numerical responses of considered aircraft, rapid analysis can be performed without necessity of computationally costly numerical aerodynamic analysis in PANUKL software package. Using optimization tools or custom written procedures all aerodynamic characteristics can be achieved by finding responses from simulation model.

As an example of possible analysis, lets consider changing lift coefficient (Cz) while maintaining longitudinal equilibrium, so having zero pitching moment coefficient as presented in Fig.8. On horizontal axis value of control point of Bezier curve are shown, which represents twist distribution. Another example shows one of many possible transition from one twist distribution to another for zero pitching moment. Cre-

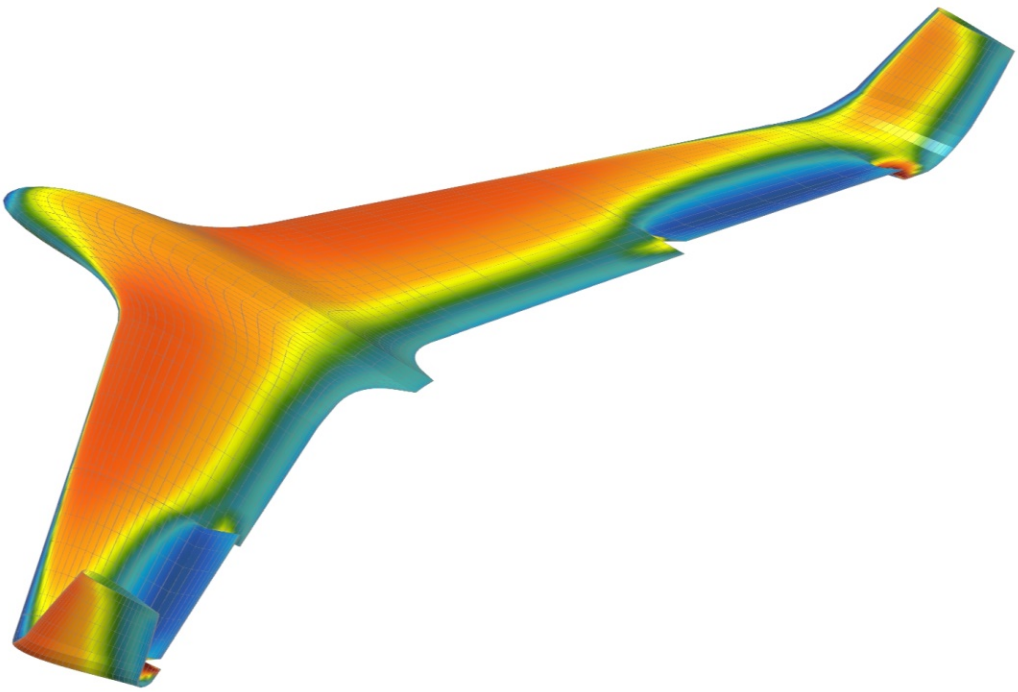

Fig. 6 NORD with aileron deflected - pressure distribution (PANUKL)

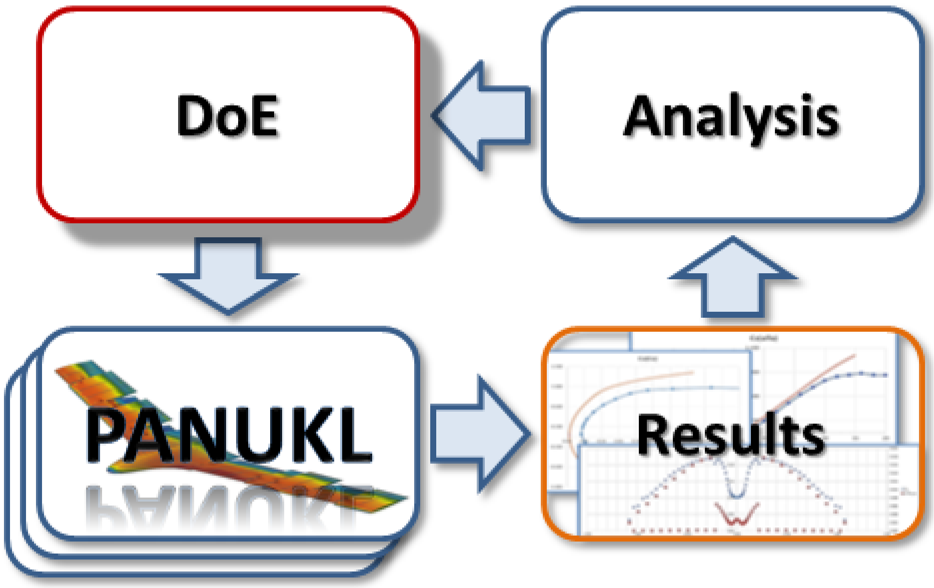

Fig. 7 Iteration loop scheme

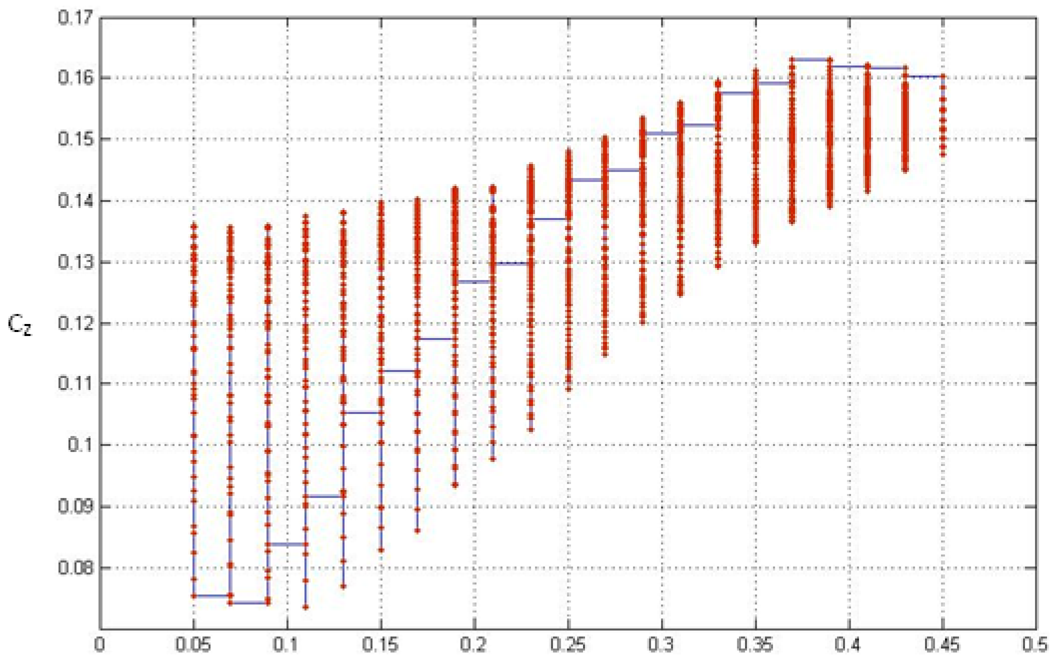

Fig. 8 Lift coefficient for zero pitching moment

ated twist distribution surface during such process is depicted in Fig.9. The variation between segments deflection in different phases of transformation is kept to minimum. Using optimization methods such transformation surface can be derived for minimum drag coefficient Cx.

The comparison of basic aerodynamic coefficients for reference and final (MORDOW) configuration is presented in Fig.10 (lift coefficient) and in Fig.11 (induced drag). Lift curve slope for discontinously morphing wing is slightly lower in comparison with refrence wing and induced drag is slightly higher.

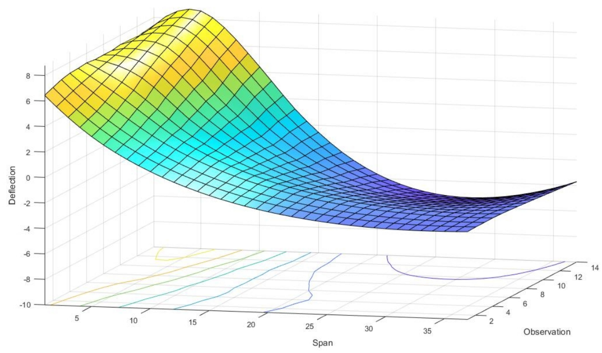

Fig. 9 Twist distribution for zero pitching moment

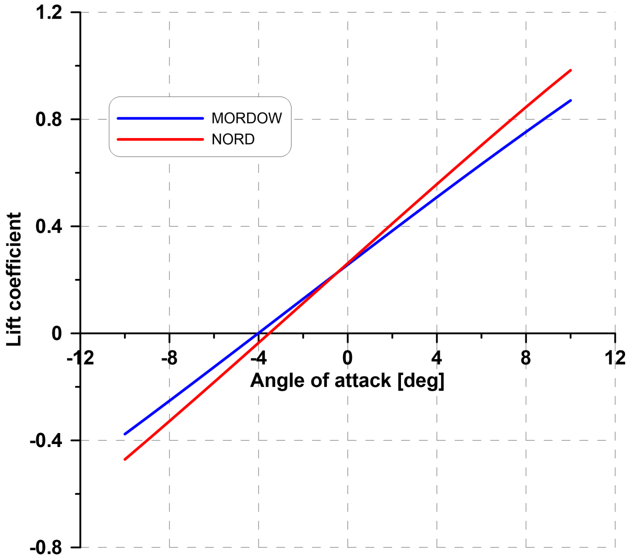

Fig. 10 MORDOW vs. NORD - lift coefficient

4 Concluding remarks

The concept of software logic and its realization in Matlab environment has been successfully verified. Matlab routines built around PANUKL package which serves as aerodynamic solver, showed robustness, parallel computation capability and correctness verified by previous results achieved in manual mode. This approach showed serious acceleration of computation time for vast sets of different flow parameters, as well as for different geometries of investigated aircraft.

The results show necessity to modify the initial design (reference wing) to obtain satisfying level of lift and stability. Removing the winglets forced the change of airfoil of morphing wing

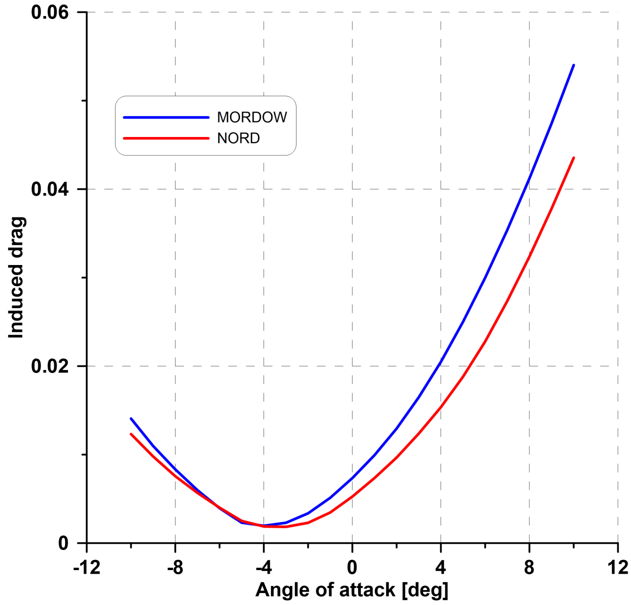

Fig. 11 MORDOW vs. NORD - induced drag

5 Future works

Future work includes the experimental verification of numerical tests in the wind tunnel as well as the assessment of the control abilities. Particulary the effectiveness of roll control by aileron (NORD) has to be compared with effectiveness of deflected segments in case of MORDOW. Other control possibilities, especially change of wing sweep and it's influence on aerodynamic characteristics are also to be verified.

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