Wind turbine blade vibration at standstill conditions – the effect of imposing time lag onto aerodynamic response

Skrzypinski, Witold Robert; Gaunaa, Mac

Publication date:
2010

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Skrzypinski, W. R., & Gaunaa, M. (2010). *Wind turbine blade vibration at standstill conditions – the effect of imposing time lag onto aerodynamic response*. Poster session presented at 2010 European Wind Energy Conference and Exhibition, Warsaw, Poland.

PO.ID
413

Wind turbine blade vibration at standstill conditions

The effect of imposing time lag onto aerodynamic response

Witold Skrzypiński
Risø DTU, Denmark; wisk@risoe.dtu.dk

Mac Gaunaa
Risø DTU, Denmark; macg@risoe.dtu.dk

Technical University of Denmark
Risø DTU
National Laboratory for Sustainable Energy

Abstract

Aeroelastic codes used for full-turbine computations assume quasi-steady aerodynamics in deep stall. Under these conditions these codes often show negatively damped edgewise blade vibrations. On the other hand, it is unlikely that the real-life aerodynamic response in deep stall is quasi-steady.
This work focused on analyzing how the aerodynamic damping is influenced by temporal lag in aerodynamic response. Therefore, it investigated whether it is inaccurate to model turbines at standstill with present aerodynamic codes.
This was achieved by introducing different amounts of temporal lag onto aerodynamic response of an elastically-mounted-airfoil model.
The analysis showed that aerodynamic damping is significantly increased even when relatively low amount of lag is introduced in the model. This indicates that present aeroelastic codes may overpredict edgewise vibrations in deep stall.

Introduction

The introduction of computational models for the dynamic aeroelastic response of wind turbines spurred numerous investigations of various dynamic issues. In some cases specific problems have necessitated evolution of sub-models in the aeroelastic computational tools. An example of such models are the dynamic stall models by Øye [1] or by Hansen, Gaunaa and Aagard-Madsen [2]. These tools model the dynamic aerodynamic response from the onset of separation until the flow over the airfoil is fully separated.

Figure 1: Broken wind turbine (www.thesun.co.uk)

The existing aeroelastic tools indicate that the edgewise vibrational mode of the wind turbine blades may be negatively damped in deep stall. Initially, it was assumed that the vibrations existed only in computations. However, turbine failures at standstill conditions reported from the industry (Figure 1) have spurred new investigations by Gaunaa and Larsen [3] as well as by Buhl [4].

These investigations concluded that the standard aerodynamics existing in aeroelastic codes for deep stall is effectively quasi-steady. Simultaneously, it is feasible that the real-life aerodynamic response is slower than quasi-steady.

The aim of this work was to analyze how the aforementioned aerodynamic damping is sensitive to time lag in the aerodynamic response. This was achieved by imposing different amounts of lag in the aerodynamic response of both nonlinear and linearized elastically-mounted-airfoil models.

Methods

The setup used in this work had been originally presented by Buhl, Gaunaa and Bak [5]. It is shown in Figure 2. *T* and *N* are the chordwise and normal-to-chord aerodynamic force components. *M* is the aerodynamic moment, α is the angle between the chord and the inflow, *x*, *y* and *θ* are degrees of freedom of the 2-D aeroelastic system with linear stiffness and damping. The hinge point is assumed to be at a quarter chord.

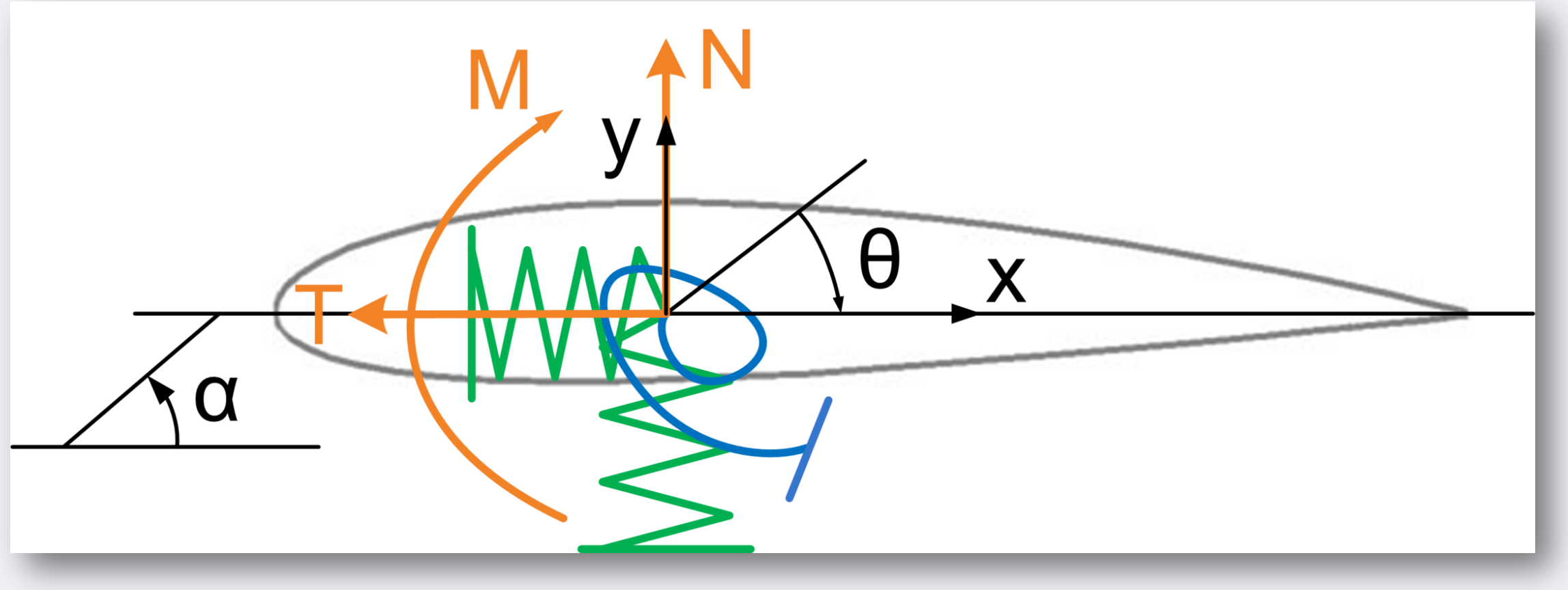

Figure 2: 2-D 3-DOF aeroelastic model, reproduced from Buhl et al [5]

Nonlinear aerodynamic model

The dynamic lift coefficient was calculated as the static lift coefficient at an effective angle of attack:

$$C_L^{Dyn} = C_L^{St}(\alpha_E) \qquad (1)$$

The effective angle of attack is the angle between the airfoil's chord and a line representing the disturbed airflow relative to the airfoil. It is calculated as:

$$\alpha_E = \alpha_{3/4}(1 - A_1 - A_2) + x_1 + x_2 \qquad (2)$$

where $\alpha_{3/4}$ is the angle of attack at the three-quarter chord. A_1 and A_2 constituted the first half of the parameters describing the aerodynamic time lag. Further, x_1 and x_2 were the aerodynamic-state variables.

The choice of parameters characterized a specific temporal behavior of the aerodynamic model. Such a choice may be visualized by means of the aerodynamic unit response function. The faster a particular function converges to 1, the closer the respective aerodynamic response is to quasi-steady. The choice of four exemplary response functions used in this study is presented in Figure 3.

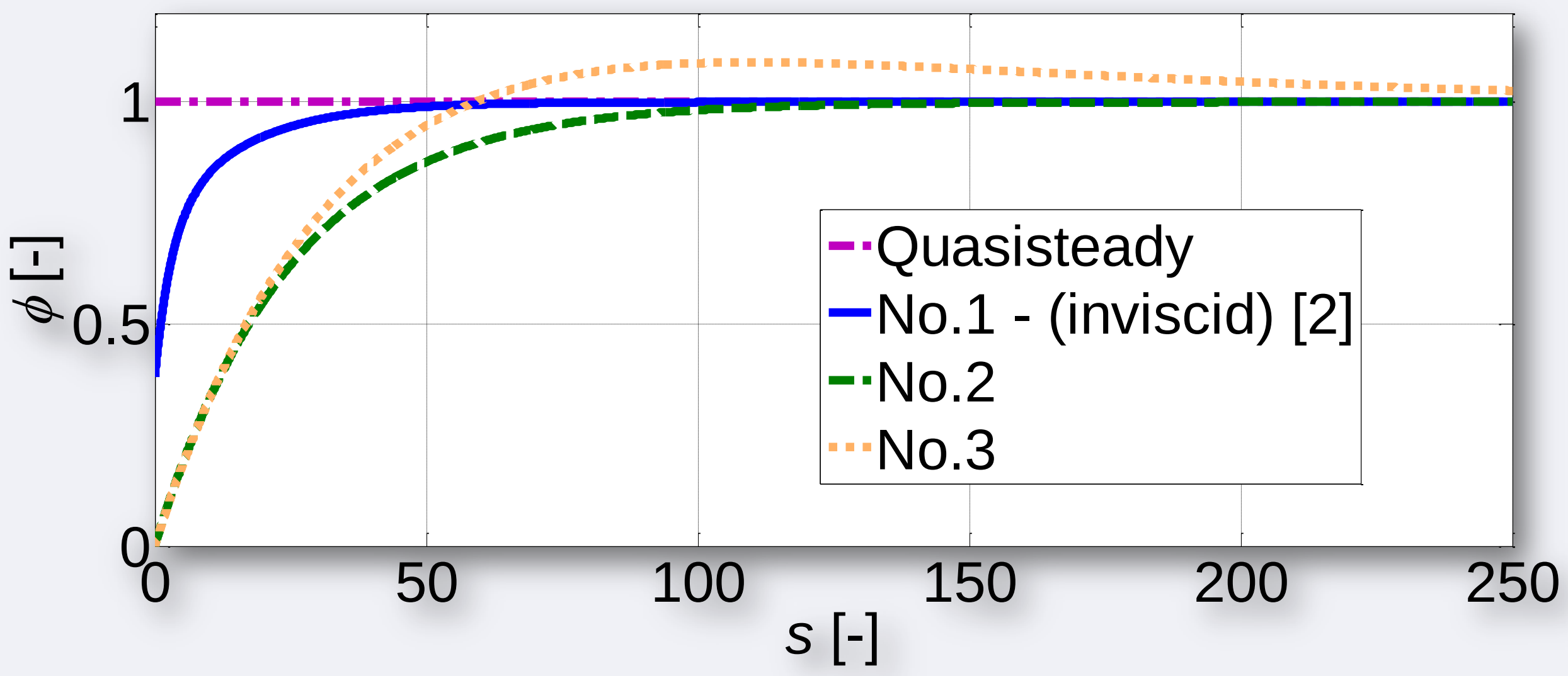

Figure 3: The four aerodynamic response functions

The quasi-steady response function corresponded to no time lag because its parameters effectively bypassed the lagging effect of the dynamic model. This corresponded to the aerodynamic response one would get from standard aeroelastic codes in deep stall. The aerodynamic response function No. 1 was an approximate representation of a thin airfoil's inviscid response [6]. The aerodynamic response functions No. 2 and No. 3 were both significantly slower than the response function No. 1.

The aeroelastic behavior - including damping characteristics - of the aeroelastic system depended on the aforementioned response functions.

Results

Figure 4 shows the damping ratios obtained by the time-domain analysis of the nonlinear system. The damping ratios coming from the aerodynamic response function No. 3 are not presented in the figure as they were very similar to the damping ratios coming from the response function No. 2.

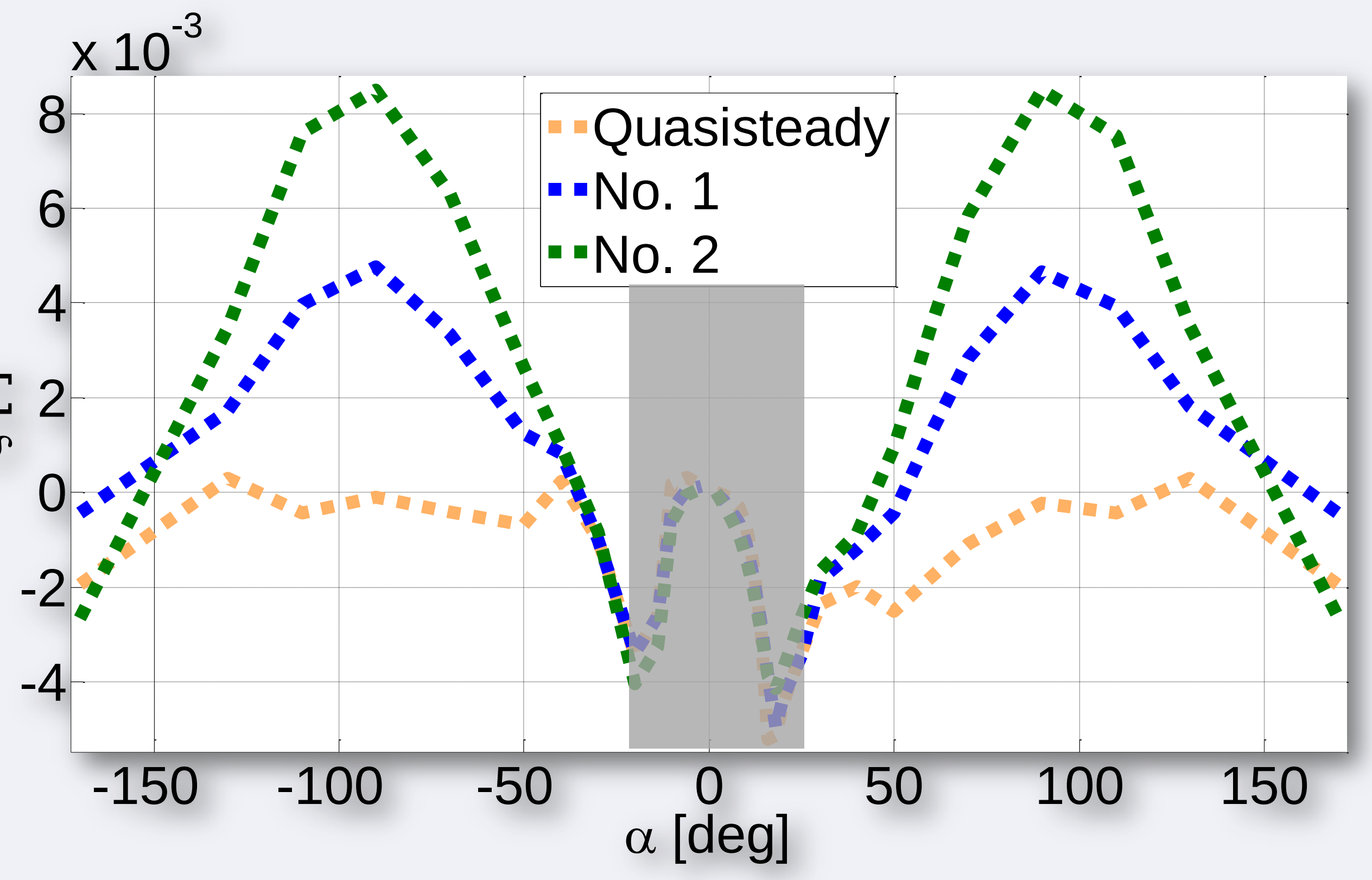

Figure 4: The damping ratios obtained by the time-domain analysis of the non-linear system; grey rectangle indicates the area out of this work's focus

The main finding of the current paper is presented in Figure 3. **The edgewise damping ratios corresponding to the lagged aerodynamic response were considerably higher than the damping ratio corresponding to the quasi-steady response.** The higher was the temporal lag of the response, the more damping was in the system.

Conclusions

The essential finding of this paper was that introducing a relatively low time lag in the aerodynamic response of a 2-D 3-DOF elastically-mounted-airfoil model significantly increased aerodynamic damping in deep stall. On the other hand, it had been previously demonstrated that the aerodynamics existing in present aeroelastic codes for deep stall is effectively quasi-steady. **These two findings indicated that these aeroelastic codes may overpredict vibration in deep stall.**

References

1. Øye, Stig: *Dynamic stall simulated as time lag of separation*, in: Proceedings of the EWEC, Thessaloniki, Greece, Oct. 1994.
2. Hansen, Morten; Gaunaa, Mac and Aagard-Madsen, Helge: *Beddoes-Leishman type dynamic stall model in state-space and indicial formulations*. Risø-R-1354(EN) (2004) 40 p.
3. Gaunaa, Mac; Larsen, Torben J.: *Stilstandslaster;* chapter in "Forskning i Aeroelasticitet" 2002, ed. Christian Bak, Risø-R-1434(DA) in Danish, Risø DTU National Laboratory for Sustainable Energy
4. Buhl, Thomas: *Edgewise vibration in stand still*, chapter in "Research in Aeroelasticity EFP-2006", ed. Christian Bak, Risø-R-1611.
5. Buhl, Thomas; Gaunaa, Mac; Bak, Christian: *Potential Load Reduction Using Airfoils with Variable Trailing Edge Geometry,* Journal of Solar Energy Engineering, Nov. 2005, Vol. 127
6. Jones, R. T.: *The Unsteady Lift of a Wing of Finite Aspect Ratio,* Tech. Rep. 681, NACA Report, 1940

European Wind Energy Conference & Exhibition 2010, Tuesday 20 - Friday 23 April 2010, Warsaw, Poland