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Extension of the Non-Linear Harmonic method for the study of the dynamic aeroelasticity of horizontal axis wind turbines

Sergio González Horcas [a,b,*], François Debrabandere [a], Benoît Tartinville [a], Charles Hirsch [a], Grégory Coussement [b]

[a] NUMECA International, 189 Ch. de la Hulpe, B-1170 Bruxelles, Belgium
[b] University of Mons, Faculty of Engineering, Fluids-Machines Unit, 53 Rue du Joncquois, B-7000 Mons, Belgium

HIGHLIGHTS

- The paper presents an innovative approach for dynamic aeroelasticity simulation.
- It couples the Non-Linear Harmonic method with a linearized structural model.
- The method is first applied to a cylinder undergoing vortex induced vibrations.
- A complete horizontal axis wind turbine is also studied, including the tower.
- Promising results are obtained, with a very good computational efficiency.

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ABSTRACT

In this paper an innovative methodology for the study of horizontal axis wind turbines dynamic aeroelasticity is presented. It can be understood as an extension of the *Non-Linear Harmonic* (NLH) method, an efficient computational approach for the analysis of unsteady periodic flows. A linearized model of the structure consisting of a set of mode shapes and natural frequencies was included. The aeroelastic equilibrium was ensured through a set of equations linking the structural displacements and the fluid loads for both the time-averaged and the harmonic contributions. First, the developed methodology is tested in the framework of a 2D cylinder mounted on a single degree of freedom elastic system and undergoing *Vortex Induced Vibrations* (VIV). The results are compared with previous experimental and computational studies, revealing the potential of the method for the prediction of both the shedding frequency and the aeroelastic response. Secondly, the dynamic aeroelasticity of the complete DTU 10MW RWT wind turbine (i.e. including the tower) is assessed. A nominal operating point is studied, and the rotor flexibility is considered via a blade structural model. The results of this *Fluid–Structure Interaction* (FSI) simulation are compared with two additional computations, both assuming *rigid* blades, that modeled the isolated DTU 10MW RWT rotor and the complete machine. This allowed to distinguish the impact of the blade flexibility on the rotor performance from the potential effects associated to the presence of the tower. In particular, the consideration of the aeroelasticity led to a decrease of the predicted time-averaged rotor loads and the corresponding amplitudes of oscillation. For its application on the DTU 10MW RWT, the developed methodology was found to be one order of magnitude faster than a standard time marching approach.

* Corresponding author at: NUMECA International, 189 Ch. de la Hulpe, B-1170 Bruxelles, Belgium.
E-mail address: sergio.horcas@gmail.com (S.G. Horcas).

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Nomenclature

Latin letters

$\mathbf{C}$	Generalized damping matrix
C_D	Drag coefficient
C_L	Lift coefficient
D	Diameter
d_n	Deformation normal to rotor axis
d_p	Deformation parallel to rotor axis
D_y	Cylinder displacement
F	Force
$\vec{F}_I$	Vector of inviscid fluxes
f_k	Spring frequency
f_{rot}	Rotor frequency
f_S	Fluid load
f_{shed}	Shedding frequency
f_{shnat}	Natural shedding frequency
F_V	Vector of viscous fluxes
$\vec{g}$	Heat flux
H	Total enthalpy
$\mathbf{I}$	Unit tensor
I	Imaginary number
k^*_{eff}	Effective stiffness
L	Span
m	Mass
p	Pressure
$\vec{q}$	Vector of generalized displacements
Q	Vector of source terms
q	Generalized displacement
R	Blade radius
r	Radial position
Re	Reynolds number
$\vec{S}$	Surface vector
St	Strouhal number
St_{shnat}	Natural Strouhal number
T	Rotation period
t	Time
$\vec{u}$	Deformation vector
U	Vector of conservative flow variables
U_∞	Freestream velocity
$\vec{v}$	Velocity vector

Greek letters

θ	Azimuth angle
ρ	Density
$\boldsymbol{\tau}$	Stress tensor
$\boldsymbol{\phi}$	Eigenvectors matrix
ξ	Damping ratio
ω	Angular velocity/Natural frequency
Ω	Volume
$\Delta\alpha$	Phase change per iteration

Subscripts

Im	Imaginary part
Re	Real part

Superscripts

$\bar{\ }$	Time-averaged
$'$	Fluctuation