Ain Shams University
Faculty of Engineering
Mechanical Power Department

Investigation of Transonic Aeroelasticity of Aircraft

By

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To

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ABSTRACT

Lifting bodies, such as wings, blades, and hydrofoils, may be subject to instabilities, such as divergence, flutter, and resonance, which can stress the structure and reduce its service life. Therefore, it is important to understand and accurately predict the response and stability of such structures to ensure their structural safety and facilitate the design. The present work numerically approach to determine flutter characteristics of the NACA0012 wing through a steady state computational fluid dynamics (CFD) simulation which provides the fluid pressure on the wing surfaces. This is then applied as a boundary condition for the finite element simulation of the configuration. Such an approach is called one-way coupled simulation since no deformation feedback to CFD. To catch the influence of the deformed wing on the aerodynamic performance, the deformation has to be brought back into the CFD solution such that an improved solution can be found and the loop can be closed. This comprises what is called two-way coupled fluid structure interaction (FSI) simulation or multiphasic simulation, which is investigated in this thesis. This work presents a three-dimensional numerical fluid-structure interaction (FSI) modeling of a vibrating wing using the commercial software ANSYS-FLUENT and investigates the aerodynamic damping as the fluid contribution to the total damping of wing flutter.

We use an FSI simulation with two separate solvers, one for the fluid (CFD) and one for the structure (FEM) that run in sequential order with synchronization points to exchange information at the interface of the fluid and structure domains. In the present work the two commercially available solvers ANSYS FLUENT 17.2 and ANSYS Classic 17.2 are applied as CFD and FEM solver respectively. Different meshes were generated in this analysis for the fluid.

As the first step and to show the basic steps in fluid-structure interaction analysis with ANSYS-FLUENT and to validate the above mentioned two-way FSI approach, oscillation of a vertical plate in a cavity filled with a fluid is considered. We also consider the transient analysis of the plate with cantilever support in dry-condition to investigate the effect of considering numerical damping in the analysis. The effects of time step and viscous damping were also studied in details.

After validating the proposed approach, special attention is paid to damping due to FSI in realistic aerodynamic conditions through the systematic application of a two-way air-wing interaction modeling in transonic regime. The capability of the two-way FSI analysis available in the software ANSYS is used to predict the amplitudes of vibration, to identify the aerodynamic damping and to estimate the influence of including FSI in the analysis of the problem. As we observe in our analysis, the damping of wing flutter is influenced by many different parameters, such as flight Mach number. The effects of considering different flow Mach numbers are also investigated. To compare the results of this research work with those obtained from the experimental observations and estimations under realistic flowing conditions, the geometry of the model was selected to be similar to the wing model used in the second test of flutter boundaries with unsteady pressure distributions done by NASA Langley Research Center [28, 29].

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NOMENCLATURE

General symbols

a	Local speed of sound
AR	Wing aspect ratio
c	Chord length of airfoil
C_α	Pitch damping by structure
C_h	Heave damping by structure
C_L	Lift coefficient
C_M	Moment coefficient
C_p	Pressure coefficient
c_p	Constant pressure specific heat
c_v	Specific heat of fluid at constant volume
$C(k)$	Theodorsen's functions
e	Air internal energy per unit mass
E_t	Total energy per unit mass(internal plus kinetic)
E, G, H	Flux vectors of flow in Cartesian coordinates
$\overline{E}, \overline{G}, \overline{H}$	Flux vectors of flow in body fitted coordinates.
EI	flexural rigidity
E_t	Is the total energy per unit volume
$\mathbf{F}$	Aerodynamic force vector
$\mathbf{f}_b$	Body force vector
GJ	Torsional rigidity
h	Heave displacement(positive upward)
h_t	Total enthalpy
I_α	Airfoil moment of inertia about support

General symbols

I_{cm}	Airfoil moment of inertia about center of mass
J	Jacobian of coordinate's transformation.
J_b	Body forces and volumetric heating source terms
k	**Element stiffness matrix**
k_α	pitch spring stiffness
k_h	heave spring stiffness
$\mathbf{K}$	System stiffness matrix
k	Vortex, thermal conductivity
k	Reduced frequency
L	Integrated aerodynamic forces, Lift
M	pitching moment act at the center of flexural axis
M	Mach number
$\mathbf{m}$	Element mass matrix
$\mathbf{M}$	System mass matrix
$\hat{n}$	Unit vector normal to surface
Pr	Prandtl number
p	Pressure
Q	Vector of flow primitive variables
q	dynamic pressure, distributed air load per length of wing surface
$\dot{q}$	Heating source
q_j	Total heat flux rate
R	Gas constant, (8314.5 $\mathrm{J\,mol^{-1}K^{-1}}$)
Re	Reynolds number
$\mathbf{S}_{ij}$	Mean strain rate tensor
S_α	Mass unbalance
t	Time (sec)