

Ain Shams University
Faculty of Engineering
Mechanical Power Department



Investigation of Transonic Aeroelasticity of Aircraft

By

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ABSTRACT

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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 multiphase 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

ABSTRACT

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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TABLES OF CONTENTS

TABLE OF CONTENTS

Abstract	i
Acknowledgments	iii
Table of contents	iv
List of figures	ix
List of tables	xiv
Nomenclature	xv
CHAPTER I: INTRODUCTION	1
1.1 Motivation	1
1.2 Aeroelasticity	2
1.3 Fluid-Structure Interaction	3
1.4 Research goal	4
CHAPTER II: LITERATURE REVIEW	5
2.1 Introduction to Transonic flow	5
2.2 development of flow field with Mach number	6
2.3 Computational Transonic flow (challenges/methods)	7
2.3.1 Early History	7
2.3.2 The (Nonlinear) Potential Revolution	7
2.3.3 Solution of Euler Equations	8
2.3.4 Linearized potential and Euler methods	8
2.3.5 Non -linear potential and Euler methods	8
2.3.6 Reynolds -Averaged Navier -Stokes equations	9
2.3.7 Computational Modelling using Inviscid Codes	10
2.3.8 Computational Modelling using Viscid Codes	10
2.3.9 The wave drag	11
2.3.10 Transonic buffet	11
2.4 transonic airfoil	11
2.5 transonic wing	12
2.6 Aeroelastic computations	12

TABLES OF CONTENTS

2.6.1	Fluid-Structure Interaction	13
2.6.2	Theory behind Fluid-Structure Interaction	14
2.6.2.1	One-Way Interaction	14
2.6.2.2	Two-way Interaction	15
CHAPTER III: THEORETICAL BACKGROUND		17
3.1	Reynolds transport theorem	17
3.2	Navier-Stokes equations	18
3.3	Reynolds-averaged Navier-Stokes equations	20
3.4	Euler Equations	22
3.5	Fully potential equation	24
3.6	Structural Mechanics	24
3.6.1	Airfoil motions	24
3.6.2	Wing motions	26
3.7	Modal analysis	27
3.8	System coupling.	28
CHAPTER IV: FLUID STRUCTURE INTERACTION (FSI)		30
4.1	Types of approach	30
4.1.1	Monolithic approach	30
4.1.2	Partitioned approach	31
4.2	The FSI Loop	31
4.3	FSI Loop Initiation	32
4.4	FSI Loop Considerations	33
4.5	Classification of FSI	34
4.6	Dynamic meshing and CFD solver	37
4.7	Prestressed Modal Analysis	38
CHAPTER V: VALIDATION		39
5.1	Oscillating of a plate in resting fluid	39
5.2	Effect of dynamic viscosity	43
5.3	Effect of numerical damping	45

TABLES OF CONTENTS

CHAPTER VI: RESULTS AND DISCUSSION	50
6.1 Modal Analysis of wing without Fluid	52
6.2 Transient Analysis of wing model without Fluid	54
6.2.1 Influence of Force Application	55
6.2.2 Influence of Force Position	60
6.2.3 Time-step study	63
6.3 Transient Analysis of Wing with Fluid (FSI)	67
6.3.1 Flow-induced vibration and influence of considering two-way FSI modeling	68
6.3.2 Influence of Force Application	71
6.3.2.1 Influence of Force Position	75
6.3.3 Influence of mesh	76
6.3.4 Influence of time step	81
6.3.5 Unsteady pressure distribution	83
6.3.6 Influence of Mach number	86
6.4 Flow separation induced by the oscillating wing in transonic flow	88
CHAPTER VII: CONCLUSIONS AND OUTLOOK	90
7.1 Objective and Conclusion	90
2.2 Future work	91
REFERENCES	92

LIST OF FIGURES

LIST OF FIGURES

Figure	Page
1.1 Schematic of the field of aeroelasticity	2
2.1 FSI components	14
2.2 Schematic drawing of a one-way coupling scheme	15
2.3 Schematic drawing of a Two-way coupling scheme	16
3.1 geometry of 2D cross section of typical airfoil	25
3.2 System Coupling - flow chart	28
4.1a Monolithic approach	31
4.1b Partitioned approach	31
4.2 Basic FSI loop	32
4.3 Initial FSI loop flow chart	33
4.4 FSI analysis setup for rigid body	34
4.5 FSI analysis setup for steady flow using System Coupling	35
4.6 Unsteady FSI analysis setup using System Coupling	36
4.7 FSI analysis setup using implicit System Coupling	37
4.8 modal analysis setup	38
5.1 (a) the oscillating plate, (b) Deformation probe on the tip of the oscillating plate	39
5.2 Fluid computational mesh	40
5.3 Streamlines of the oscillating plate (a) 2D, (B) 3D	40
5.4 Horizontal displacement of the free end of the plate (a) $\Delta t=0.1s$, (b) $\Delta t=0.01s$	42
5.5 Compare the plate horizontal displacement for different time steps ($\mu=0.2$, $ND=0.1$, $\beta=0$)	42
5.6 Comparison of displacements between present study with Tahereh Liaghat-2014, and Glück, M.-2001 results ($\mu=0.2$, $ND=0.1$, $\Delta t=0.01s$)	43
5.7 Horizontal displacement of the free end of the plate for different fluid viscosities ($\mu=1$, $\mu=0.2$) pa.s, $ND=0.1$	44

LIST OF FIGURES

5.8	Comparison of displacements between present study with Tahereh Liaghat-2014, and Glück, M.-2001 results ($\mu=1, ND=0.1, \Delta t=0.01s$)	44
5.9	Horizontal displacement of the free end of the plate ($ND=0.01, \Delta t=0.1s$)	45
5.10	Horizontal displacement of the free end of the plate for different numerical damping (ND)	46
5.11	Horizontal displacements of the free end of the plate for different material damping (β)	46
5.12	Horizontal displacements of the free end of the plate for different Δt and ND (with $\mu=0, \beta=0.1$)	47
6.1	NACA0012 Model details	51
6.2	Domain of flow computation	51
6.3	Schematic diagram of flow near wing surface	52
6.4	Plunge Mode (3.352Hz-PAPA)	54
6.5	Pitch Mode (5.22Hz-PAPA)	54
6.6	Y[m] displacement of the wing for different (t_f)	58
6.7	(a) Y-displacement of the wing (b) FFT of the system response	59
6.8	(a) Y-displacement of the wing (b) FFT of the system response	60
6.9	(a) plunge displacements of the wing (FT=60 N, FL=0 N) (b) FFT of the system response	61
6.10	(a) plunge displacements of the wing (FT=30N, FL=-30N) (b) FFT of the system response	62
6.11	(a) plunge displacements of the wing (FT=15N, FL=-30N) (b) FFT of the system response	62
6.12	(a) plunge displacements of the wing (FT=0 N , FL=-60 N) (b) FFT of the system response	62
6.13	6-13 plunge displacements of the wing , $dt=0.01$ s	64
6.14	plunge displacements of the wing , $dt=0.005$ s	64
6.15	plunge displacements of the wing , $dt=0.001$ s	64
6.16	plunge displacements of the wing , $dt=0.0001$ s	65
6.17	plunge displacements of the wing (For different time steps)	66
6.18	FFT of the system response (a) $dt=0.0001$ s (b) $dt=0.001$ s	66
6.19	Aerodynamic forces on the wing	69

LIST OF FIGURES

6.20	FFT response of reaction forces a) one way b) two way	70
6.21	one way/ two way plunge displacements of the wing	70
6.22	FFT response of plunge displacements a) two-way b)one-way	71
6.23	Contour of vortices at the trailing edge of the wing	71
6.24	plunge displacements for different t_f	73
6.25	FT=30 N , FL=-30 N (a) plunge deformations of wing (b) FFT of the system response	75
6.26	Different Fluid meshes (a) C-mesh (b) M-mesh (c) F-mesh	76
6.27	plunge deformation of the wing for different meshes	79
6.28	Pitch deformation of the wing for different meshes	80
6.29	plunge deformation of the wing for two time steps	83
6.30	Unsteady pressure statistics (M_Mesh,upper surface)	84
6.31	Unsteady pressure statistics (F_Mesh, upper surface)	84
6.32	mean C_p F_Mesh, M_Mesh,experimental	85
6.33	Time history of Unsteady Pressure at point (X/C=0.25)	85
6.34	plunge deformation of the wing for different Mach numbers	87
6.35	pitch deformation of the NACA0012 wing (pure pitch)	88
6.36	Contours of total pressure around a pure pitching NACA0012 wing in one pitch cycle[peak to peak =2.3°]	89

LIST OF FIGURES

List of Tables

Table		Page
5.1	Natural frequency of the plate in dry conditions	41
5.2	Parameters to investigate the effects of numerical damping and time step (Dry-condition)	49
6.1	Structural Characteristics of PAPA (NACA0012 rigid wing)	52
6.2	Natural frequencies of the wing (PAPA) in dry-condition	53
6.3	Modal displacements of the wing (PAPA)	53
6.4	Different forcing functions for transient analysis of the wing model	55
6.5	Step Force with different time durations (t_f)	56
6.6	Dominant frequencies and maximum amplitude of plunge-vibration for different time steps	63
6.7	Free stream condition of the simulations	67
6.8	Step force with different time durations (tf) for wing air interaction	72
6.9	FSI vibrations for different (t_f)	74
6.10	Three different fluid meshes	77
6.11	FSI plunge displacements of wing for different meshes for fluid domain	78
6.12	FSI pitch displacements of wing for different meshes of fluid domain	79
6.13	Differences between M-Mesh and F-Mesh	80
6.14	plunge deformations of the wing for different time steps	82
6.15	Two different time step (M_Mesh)	82
6.16	plunge deformations of the wing for different Mach numbers	86

NOMENCLATURE

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
$\bar{E}, \bar{G}, \bar{H}$	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

NOMENCLATURE

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
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
m	Element mass matrix
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, ($8314.5 \text{ J mol}^{-1} \text{ K}^{-1}$)
Re	Reynolds number
S_{ij}	Mean strain rate tensor
S_α	Mass unbalance
t	Time (sec)