



Coupled Fluid-structure Flutter Analysis of a Transonic Fan

ZHENG Yun, YANG Hui*

School of Air Propulsion, Beihang University, Beijing 100191, China

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Abstract

A coupled fluid-structure method is developed for flutter analysis of blade vibrations in turbomachinery. The approach is based on the time domain solution of the fluid-structure interaction in which the aerodynamic and structural equations are marched simultaneously in time. The three-dimensional (3D) unsteady Reynolds average Navier-Stokes (RANS) equations are solved with a multiblock finite volume scheme on dynamic deforming grids to evaluate the aerodynamic force. Dual time-stepping technique and an efficient implicit scheme with multigrid are employed to march the solution in time. The blade vibration is modeled with an aeroelasticity model in which blade motion is computed by linear combination of responses of each mode under unsteady loads. The code is validated in prediction of the unsteady flow flutter behavior of an oscillating cascade and is applied to flutter analysis of a transonic fan at the design speed.

Keywords: transonic flow; unsteady flow; flutter; transonic fan; fluid-structure interaction; turbomachinery

1. Introduction

The design trends for modern commercial aircraft engine are towards high thrust/weight ratio, fuel efficiency and safety^[1]. These requirements lead to design fans and compressors with high pressure ratio per stage, thin blades, making the blades more susceptible to fluid induced vibration. Flutter is known as a self-excited vibration of a body in fluid. It poses significant challenge to aero-engine safety. Furthermore, aeroelastic stability causes designers to be conservative in pushing the design of engines to new limits of performance^[2]. Prediction flutter with numerical methods is critical for both the safety and the improvement of the aero-engine performance.

Flutter is a multidisciplinary subject combining unsteady aerodynamics and structural dynamics. The simultaneous integration of the equations of motion

in time for the fluid and structure allows the correct assessment of the energy exchange between fluid and the blade(s). Flutter occurs when the blade absorbs energy from fluid and the blade vibration becomes unstable. When the aero-damping of fluid dissipates the vibrating blade energy, the amplitude of the vibration reduces, and thus the vibration is stable. When a balance between input energy and dissipation occurs, the blade enters auto-oscillation or limit-cycle oscillation mode (LCO)^[3], in which the oscillation amplitude is critical to assess its impact on structure integrity. Flutter is usually associated with fan blades, though other compressor and low-pressure turbine blades may also suffer from such instabilities^[4].

Prediction of blade flutter is proven to be a difficult task due to the perplexing phenomena of fluid-structure interaction in turbomachinery. In addition, people do not fully understand the consequences of many additional features, such as flow distortions due to blade-row interaction, coupling of assembly modes, and loss of spatial periodicity (aerodynamic or structural mistuning), acoustic resonance, etc. Time-linearized (frequency domain) approach has

*Corresponding author. Tel.: +86-10-82319391-105.

E-mail address: huiyang@buaa.edu.cn

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