IN-34-CR
2 REF
121532

Final Technical Report

for

Euler/Navier-Stokes Solvers Applied to Ducted Fan Configurations

NASA Grant Number
NAG3-1230

Grant Duration
December 20, 1990 to December 20, 1996

Theo G. Keith, Jr.
Principal Investigator
Rakesh Srivastava
Co-Principal Investigator

Department of Mechanical, Industrial and Manufacturing Engineering
University of Toledo
Toledo, Ohio 43606

December 1997

EULER/NAVIER-STOKES SOLVERS APPLIED TO DUCTED FAN CONFIGURATIONS

Introduction

Due to noise considerations, ultra high bypass ducted fans have become a more viable design. These ducted fans typically consist of a rotor stage containing a wide chord fan and a stator stage. One of the concerns for this design is the classical flutter that keeps occurring in various unducted fan blade designs. These flutter are catastrophic and are to be avoided in the flight envelope of the engine. Some numerical investigations by Williams, Cho and Dalton [1], have suggested that a duct around a propeller makes it more unstable. This needs to be further investigated.

In order to design an engine to safely perform a set of desired tasks, accurate information of the stresses on the blade during the entire cycle of blade motion is required. This requirement in turn demands that accurate knowledge of steady and unsteady blade loading be available. Aerodynamic solvers based on unsteady three-dimensional analysis will provide accurate and fast solutions and are best suited for aeroelastic analysis. The Euler solvers capture significant physics of the flowfield and are reasonably fast. An aerodynamic solver Ref. [2] based on Euler equations had been developed under a separate grant from NASA Lewis in the past. Under the current grant, this solver has been modified to calculate the aeroelastic characteristics of unducted and ducted rotors.

Even though, the aeroelastic solver based on three-dimensional Euler equations is computationally efficient, it is still very expensive to investigate the effects of multiple stages on the aeroelastic characteristics. In order to investigate the effects of multiple stages, a two-dimensional multi stage aeroelastic solver was also developed under this task, in collaboration with Dr. T. S. R. Reddy of the University of Toledo. Both of these solvers were applied to several test cases and validated against experimental data, where available.

Summary of Accomplishment

The aerodynamic solver developed in Ref. [2], for solving flowfield around unducted propellers, was extended to solve flows around ducted propeller geometries. This involved modifying the solver to account for additional radial partitioning of the flow domain, and the boundary condition, to allow both internal and external flow solution. Modifications were also required to grid generation routines. The results obtained have been documented in Ref. [3].

The solver in [2] was also modified to study the aeroelastic behavior of the propeller blades, both in time domain and frequency domain. This required additional routines to be added to the solver for solving modal structural dynamics equations. This was achieved with the help of Dr. T. S. R. Reddy of the University of Toledo. The aerodynamic loads obtained on the blades are used in the structural dynamics equation on the right hand side as a forcing function. The structural dynamic equations are then solved to obtain the new position of the blades. In time domain analysis, the blades are perturbed from a steady state and the iterations are carried out to see whether the perturbations grow or decay. A growing perturbation indicates aeroelastic instability. This approach was used to calculate the flutter boundary of the SR3C-X2 propfan observed in wind tunnel tests at NASA Lewis. The results obtained, agree well with the measurements and have been documented in Ref. [4].

In the frequency domain analysis, the blade is prescribed a motion and the unsteady aerodynamic loads are obtained. These loads are then Fourier analyzed to obtain the aerodynamic damping present in the system. A negative aerodynamic damping indicates the blades to be unstable. This modification also required additional routines for prescribing the blade motions and for the analysis of the unsteady air loads. The same case, studied for time domain analysis, was used in the frequency domain analysis as well. The results obtained are also documented in Ref. [4].

To investigate the effects of multiple blade rows, a 2-D aeroelastic solver for single row cascade was modified. This solver is based on a finite volume based 2-D Euler solver. The original solver was applicable only to single row of cascades. Under the current task, it was extended for solving Euler equations around relatively moving multiple rows of cascades. This is a 2-D representation of rotor-stator type configuration. The scheme for updating the relatively moving boundary of the two cascades was adapted from the method developed for counter rotating propfans by Srivastava and Sankar in Ref. [5]. This scheme has been successfully applied to several multiple row cascades and the results have been documented in Refs. [6] & [7].

An automated process for obtaining static stability and deformed operating shape of the blades was also developed under the current task. This process solves iteratively a set of aerodynamic equations for obtaining the blade loads which is then used in structural analysis to obtain the blade deflections. These deflected shapes are then used to obtain the new set of loads. This whole process is repeated until a converged shape is obtained or the blade shows instability. For this purpose the solver reported in [8] by Srivastava *et al.* was coupled in an open loop fashion with NASTRAN. The automated process was used to obtain the deflected blade shape of F-39 forward swept blades. The results obtained have been reported in Ref. [9].

The aerodynamic code developed in Ref. [3] for ducted rotor analysis was also extended for calculating the aeroelastic characteristics. The ducted aeroelastic analysis code based on Euler equations was thoroughly checked for consistency and applied to a ducted fan geometry. The fan geometry was obtained by modifying an existing porpfan geometry. Flutter analysis was carried out both for unducted and ducted rotor configurations. The results obtained corroborated the observations made by Williams, Cho and Dalton [1] and showed that addition of a duct to this rotor made the unducted propfan dynamically unstable. These results have been summarized in Ref. [10] for time domain and in Ref. [11] for frequency domain.

User's manual were also written for both the two-dimensional multistage aeroelastic solver MSAP2D [12] and the multi passage propfan aeroelastic code PROP3D [13]. These manuals consists of providing the user with definition of input and output files and variables, a few sample input and output files and tips and information on productively using the codes.

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