Study of a Practical Analysis Method for Transonic Wing Flutter

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■Introduction

Flutter is self-excited vibration phenomenon which is one of the aeroelastic phenomena and occurs by a mutual interaction of aerodynamic force, inertial force, and elastic force. Usually, structural oscillation is damped by aerodynamic force but catastrophic oscillation occurs at a certain flutter speed. And in the worst case, it brings about wing destruction instantly. Wing flutter is a very dangerous phenomenon.

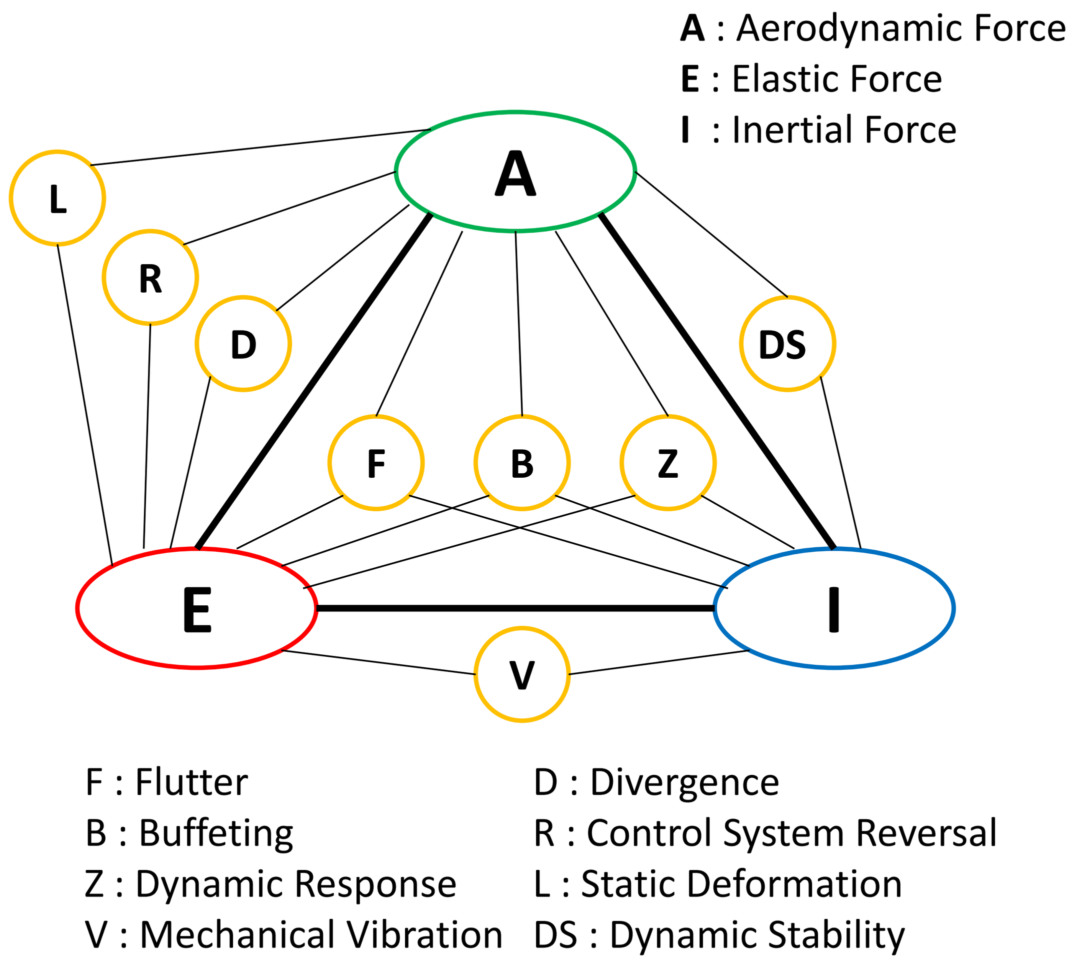

Fig.1 Aeroelastic Phenomena

Fig.2 Flutter Phenomenon
(http://www.dg-flugzeugbau.de/index.php?id=dg1000-flattern-e)

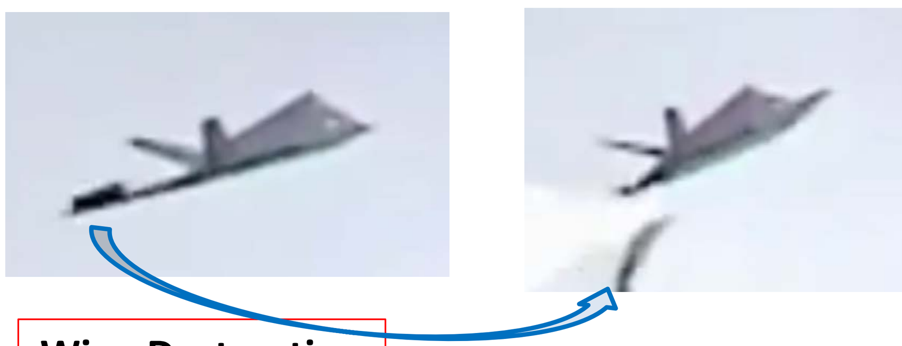

Fig.3 Airplane Crash
(https://youtube.com/watch?v=X2wYvr20nAg)

■Transonic Dip Phenomenon

Sudden a decline of flutter boundary in Transonic region

- Caused by unsteady behavior like shock wave and detached flow
- Important property to analyze flutter phenomenon

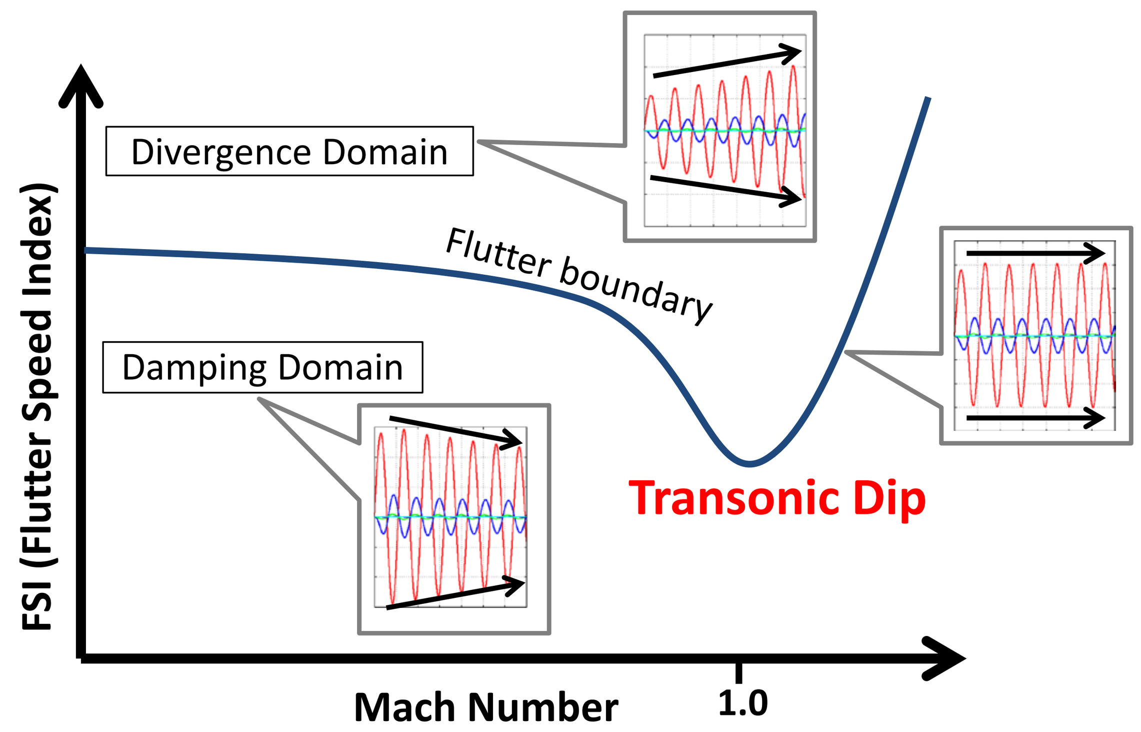

Fig.4 Transonic Dip Phenomenon

■Past Accidents

- Handley Page O/400 bomber (1916, UK)
- Control surface flutter (World War Ⅰ)
- Midair breakup accidents (World War Ⅱ)
- F117 fall accident (1997, U.S.)

Avoiding flutter is essential for safe flight

Fig.5 Handley Page O/400 bomber
(http://en.wikipedia.org/wiki/Handley Page Type O)

Fig.6 Next Generation Airplane
(http://www.newairplane.com/787/#/galler)

■Design of Next Generation Airplanes

- Lightweight airframe
- High aspect ratio main wing

} Deterioration in prediction capability

- Total number of simulation : about 2.5 million

Need to develop a numerical method which can predict flutter boundary more accurately and less computational cost

■Common Analysis Method

Linear - DLM(Doublet Lattice Method)

○ : High computational efficiency

× : Inadequate analysis accuracy at transonic region

Nonlinear - Analysis using Euler/Navier-Stokes Equation

○ : Adequate analysis accuracy at all region

× : Low computational efficiency

■Objectives

- Develop a numerical method which can predict transonic flutter with far less computational cost while retaining capability of capturing transonic dip phenomenon
- Compare experimental data and computational result which is calculated in this study and calculated by Euler/Navier-Stokes equation and confirm accuracy and computational time

■Flutter Analysis Method

Use Fluid-Structure Interaction Analysis to analyze flutter phenomenon

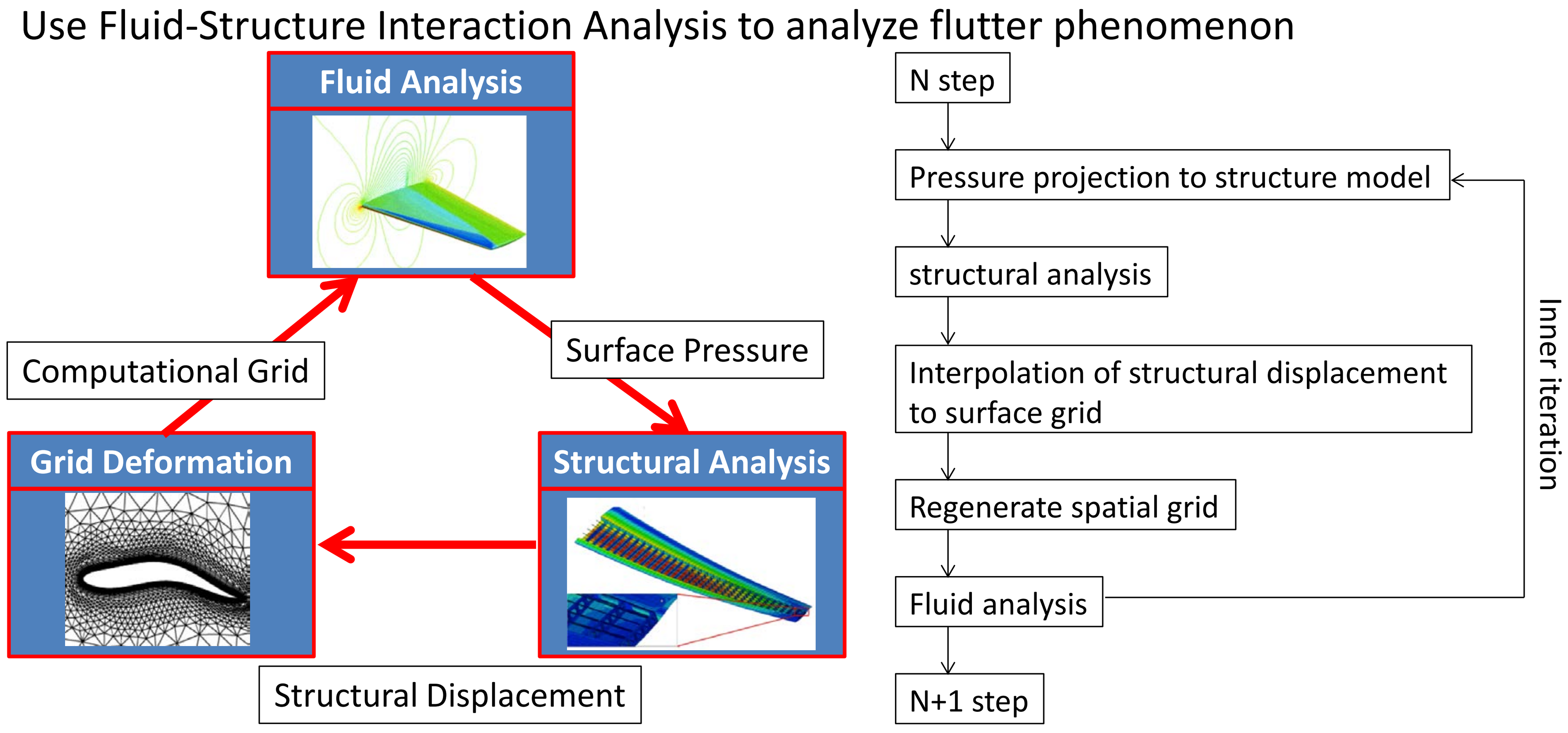

Fig.7 Calculation Flow

- Structural Analysis

Governing Equation	Equation of motion
Analytical Procedure	Modal Analysis
Time Integration	Three level backward difference

- Spatial Grid Deformation

Grid Regeneration	Algebraic method

■Unsteady Aerodynamic Modeling

Model simplification

Navier-Stokes Equation
- Second order nonlinear partial differential equation in six variables
- Takes into account viscosity

Euler Equation
- First order nonlinear partial differential equation in six variables
- Neglects viscosity

Full Potential Equation
- Second order nonlinear partial differential equation in two variables
- Neglects vorticity and entropy production

Transonic Small Disturbance Equation
- Second order nonlinear partial differential equation in two variables
- Assumes a small disturbance

Laplace Equation
- Second order linear partial differential equation in one variable
- Assume a steady, low subsonic and incompressible flow

Practical modeling method which can capture the transonic dip phenomenon with less computational cost

Select full potential equation to suggest less computational cost and more accurate analysis method

■Present Works

I'm now writing an analysis program using the full potential equation which can predict transonic flutter phenomenon.

From past studies, the computational results calculated by Euler and RANS equations for AGARD445.6 wing have already been obtained. Evaluation of their equations takes a few days to predict flutter boundary. It is not said that Euler and RANS equations are a practical modeling method. Figure 8 shows flutter boundary obtained from past studies. Vertical and Horizontal axis are FSI(flutter speed index) and Mach number respectively. This shows good agreement with experimental data in subsonic region but predicts higher flutter boundary in supersonic region. It is thought that these methods couldn't capture the effect of interference of shock wave and boundary layer accurately.

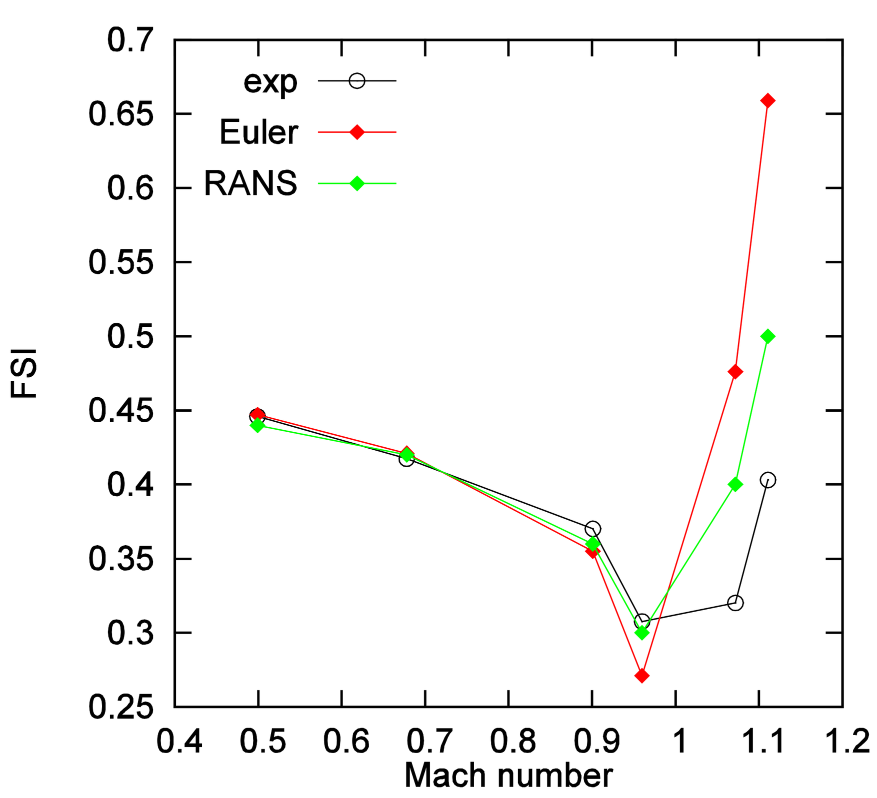

Fig.8 Flutter Boundary

■Future Plans

・Predict flutter boundary of AGARD445.6 wing by full potential analysis program

・Insert the boundary layer equation and take into account the effect of viscosity

・Compare experimental data and computational result which is calculated in this study and calculated by Euler/Navier-Stokes equations, then confirm accuracy and computational time