DCTA/IAE Aeroelasticity Branch
Theoretical and Experimental Aeroelasticity Activities

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Outline

- Applied Aeroelasticity
- Research and Development
- Academic Activities
  - Graduate and undergraduate programs
Aerodynamics Division IAE/ALA-L

- Applied Aeroelasticity and Aerodynamics:
  - Roberto Gil Annes da Silva, DSc - ITA, 2004
  - Adolfo Gomes Marto, DSc - UNICAMP, 2002
  - Carlos Eduardo de Souza, MSc - UFRGS, 2003

- Computational Fluid Dynamics:
  - Edson Basso, MsC - ITA, 1998
  - João Luiz Filgueiras de Azevedo, PhD - Stanford, 1987
Applied Aeroelasticity

**FLUTTER CLEARANCE PROCESS**

- Ground Vibration Test (GVT)
  - IAE Test and Integration Lab (AIE) provide support in:
    - Ground Vibration Tests (GVT) of aircraft and stores
    - Ground Vibration Tests (GVT) of UAV systems
    - GVT of several wing/pylon mounted stores
- Structural dynamics modeling of complete aircraft and subsystems (pylons and stores)
- Flutter Clearance / Aeroelastic Stability Analysis
  - Structural and Unsteady Aerodynamics Modelling
  - Aeroelastic analysis for external stores qualification;
- Flutter Flight Test (FFT) - Flight Tests Squadron (GEEV)
External Stores Aeroelastic Certification Activities

- Applied aeroelasticity for weapons integration:
  - Core business activity
  - ZAERO and NASTRAN
  - In house developed aeroelastic analysis blockset: (MATLAB + C++)
    - Non planar doublet lattice
    - State space aeroelastic module – RFA for aeroelastic stability and response
    - Pre and post processing – flutter solutions
Ground testing

- Ground Vibration testing
  - Structural dynamic models calibrated through GVT
  - Clamped pylon stores systems – FEM model update
  - UAV systems

6th mode - theoretical

6th mode - experimental
Ground Vibration Test (GVT)
Structural Dynamic Modeling

Embraer A-1A/B (AMX)

6th mode - experimental

6th mode - theoretical

2nd mode - experimental

2nd mode - theoretical

Northrop F-5E/F Tiger II
Aeroelastic Analysis

- Aircraft:
  - Northrop F-5E/F
  - Tiger II
  - EMBRAER A-1A/B (AMX)
- Computational tools - software
  - MSC/NASTRAN with DMAP/AERO II options (subsonic and supersonic range)
  - ZAERO Software System
  - Other in-house developments for aeroelastic analysis.
Applied Aeroelasticity – Brazilian Air Force Aircraft

- BAF’s fighters
  Modernization programs:
  - F-5Br
  - A-1M
- In house developed weapons systems
  - MAR-1 missile
  - MAA-1A/B missiles
  - General purpose bombs / dispensers
- Other foreign weapon systems
Other Activities – Space Systems

- Aerothermoelastic analysis of sounding rockets
- Supersonic flow, Mach = 4.0
- Fin attached to body of revolution

Temperature distribution

Pressure distribution

Fin FEM model
Sounding Rockets Aeroelasticity

- Paper presented at IFASD 2007

**A SENSITIVITY INVESTIGATION ON THE AEROELASTIC DYNAMIC STABILITY OF SLENDER SPINNING SOUNDING ROCKETS**

Roberto Gil Annes da Silva¹, J. Guido Damilano² and João Luiz F. Azevedo³
In-flight Aeroelastic Testing: Research Activity ↔ Aeroelastic Applications
Comparison of in-Flight Measured and Computed Aeroelastic Damping: Modal Identification Procedures and Modeling Approaches

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OMA, or Operational Modal Analysis is a technique often used in civil engineering and automobile industry;

It requires only the knowledge of output measurement to set up an “input”/output relation for system dynamic identification purposes;

“Input” assumed to de a white noise.
Methodology

- Theoretical Aeroelastic Model;
- Fight Test Procedures/Proposal
- Instrumentation/Data Acquisition;
- Operational Modal Analysis (OMA);
- Modal Parameters Synthesis
- Theoretical – Experimental Damping Correlation
Flight tests

- Instrumented Aircraft – F-5E;
  - 16 Accelerometers;
  - Wiring;
  - Data acquisition system.
- Tested Configuration;
  - Clean A/C (without wing tip missiles).
- Test points:
  - Fixed altitude (density);
  - Mach number increments.
- Airframe Excitation;
  - Atmospheric turbulence.
- Sampling rate:
  - 1024 Hz;
Conclusions – Lessons Learned

- Operational Modal Analysis assuming continuous turbulence as input excitation is a promising methodology for aeroelastic modal parameter identification.
- The hypothesis assumed regarding the continuous turbulence being considered as a white noise input led to reasonable results within a low frequency range assumed for instance, of interest in this work.
- After reducing the data from tests by B&K OMA® software, using the EFDD (Enhanced Frequency Domain decomposition) identification method, it was possible to clearly identify the aircraft first four modes of vibration, at reasonable modal parameter values consistent with the theory.
- Even though some accelerometers signals observed saturation at flight conditions within the high subsonic regime, the overall quality of the results are good.
- It is also concluded from the results presented that special care should be taken when using OMA for experimental flutter speeds identification, either by damping extrapolation, or by a flutter margin criterion.
Research and Development

- Developments for applied aeroelasticity
  - Aeroelastic analyses tools
  - Aeroelastic flight testing – System Identification - OMA

- Flight dynamics of aeroelastic vehicles
  - Flight dynamics and loads analyses

- Smart Materials application for aeroelastic control (Academic research level)
  - Wind tunnel aeroelastic testing
  - Nonlinear aeroelasticity
Computational Aeroelasticity Research

- Institute of Aeronautics and Space – Aeroelasticity and CFD Branches;
  - Geometric Modeling: (Applied Math Dept.)
    - Data structure, Elastic meshes, interpolation of the domain properties; immersed boundary technique: direct numerical simulation of flows around geometrically complex bodies; Mesh adaptive refinement: mesh refinement based on flow properties; code parallelization: development of a parallelization techniques for code distribution in a cluster environment;
Computational Aeroelasticity Research

  - Aeroelasticity: (IAE, Aeronautical Eng. Dept.)
  - Mathematical model for two- and three-dimensional unsteady subsonic and transonic aerodynamics;
  - Two and three-dimensional aeroelastic modeling for subsonic and transonic flow regimes;
  - Effects of shock/boundary layer interaction in transonic flutter;
  - Development of methods for mesh dynamics and applications of geometric modeling in aeroelastic problems;
  - Wind-off wind tunnel model design and characterization;
  - Experiments and data reduction;
  - Non-linear aeroelastic phenomena;
  - Correction methods for transonic flutter analysis;
  - Chimera unstructured mesh technique;
  - Code parallelization: development of a parallel version of the code;
3D Finite Volume Aeroelastic Solver Unstructured
(Research Project Goal)

Data structure
Elastic meshes
Complex configs.
Parallel Processing

WT model tests
Data reduction
Code validation database
Nonlinear Aeroelasticity

2D Finite Vol. Aeroelastic Unstructured
3D Finite Diff. Unsteady Aerodynamics Structured
3D Finite Vol. Steady Aerodynamics Unstructured
Computational Aeroelasticity Research

- Unsteady 3D CFD code (code from Dr. Sankar – GTech):
  - Structured 3D Navier-Stokes unsteady flow solver
  - Only for prescribed motions;

- Research codes developed by the CFD Branch (Dr. Azevedo – IAE)
  - Unstructured (Cell centered) 3D Navier-Stokes Finite-Volume Solver;
  - Unstructured (Cell centered) 2D Euler Finite-Volume Aeroelastic Solver;
2D CFD Aeroelastic Modeling

- 2D Aeroelastic modeling for subsonic and transonic flow regimes;
Research Focused on Aeroelastic Applications

- Research conducted by the Aeroelasticity Branch
  - Aeroelastic Solver in State Space
    - Doublet Lattice and Strip Theory Aerodynamics + rational function approximation – State Space Aeroelastic modeling – flight dynamics of aeroelastic vehicles
  - Correction methods for transonic flutter analysis
    - Downwash Correction Methods
    - Successive Kernel Expansion Method (collaborative work with ZONA Technology);
  - Generalized Vortex Lattice Method for Aeroelastic Analysis
    - Unsteady aerodynamic models to be integrated in the state space aeroelastic solver – supersonic flow
Other Research Interests

- Expedient procedures for aircraft/store flutter clearance
  - Automated procedures for rapid flutter clearance for multiple external stores configurations
  - Aircraft/stores structural dynamic model update from GVT data.

- Experimental Aeroelasticity
  - Wind tunnel Aeroelastic models – design and construction of low cost aeroelastic models
  - Operational Modal Analysis applied to flutter flight testing
Academic Activities – ITA

Graduate Studies:

- Aeronautical and Mechanical Engineering program
- Aeroelasticity related disciplines:
  - AA-220 Unsteady Aerodynamics
  - AA-222 Applied Aerodynamics to Aeroelasticity
  - AE-225 Structural Dynamics I
  - AE-228 Structural Dynamics II
  - AE-249 Aeroelasticity I
  - AE-250 Aeroelasticity II
  - AB-267 Dynamics and Control of Flexible Aircraft
Academic Activities – ITA

Undergraduate Studies:

- **Aeronautical Engineering**: Aeroelasticity related discipline:
  - EST-56 – Structural Dynamics and Aeroelasticity
Current Research Topics

- **PhD Dissertations**
  - Aeroelastic control based on Shape Memory Alloys (Prof. Goes)
  - Aeroelastic control based on Magneto-Rheological Dampers (Prof. Goes)
  - Lightweight Structures Aeroelastic Modeling – Composite Materials (Prof. Gil)
  - Flight Dynamics of Highly Flexible Aeroelastic Vehicles (Prof. Paglione / Prof. Gil)
  - Nonlinear Optimum Robust Control of Flexible Aircraft (Prof. Yoneyama / Prof. Paglione)
Current Research Topics

- **MSc Thesis (Profs. Goes, Gil, Paglione)**
  - Aeroelastic Control – MFC (Macro Fibers Composite)
  - Wind tunnel aeroelastic testing of light weight structures
  - System identification of aeroelastic systems
    - In-flight aeroelastic system response identification
    - Wind tunnel models - aeroelastic system identification
  - Approximate transonic flutter solutions based on correction methods
  - Aeroelastic dynamic response – Matched Filter Theory
  - Nonlinear aeroelastic analysis - control surface freeplay
  - Flight dynamics of aeroelastic vehicles
  - Wing weight optimization based on aeroelastic sensibility analyses
  - T-Tail flutter analysis methods