Fluid-Structure-Coupling Using the TAU Code: Developments and Applications at the DLR Institute of Aeroelasticity

Wolf Krüger
DLR Institute of Aeroelasticity
Fluid-Structure-Coupling at the Institute of Aeroelasticity
Current activities and projects involving the TAU code (1)

- **Focus on applications:**
  - Fluid-structure coupling with large (industrial) models
  - Coupling of fluid, structure and flight mechanics using CFD

- **Focus on development of methods:**
  - Improvement of fluid-structure coupling schemes in the space domain
  - Investigations and development of coupling algorithms in the time domain

- **Focus on understanding the physical background:**
  - Transonic aeroelasticity, limit cycle oscillations, buffet, boundary layer modelling, wing/engine interference, wing/control surface interference, thermo-fluid-structure-coupling
Fluid-Structure-Coupling at the Institute of Aeroelasticity
Current activities and projects involving the TAU code (2)

TAU is used for

- Pre-processing
- Solver
- Post-processing
- Deformation tool

TAU is used in

- DLR projects HighPerFlex, SikMa, MegaOPT
- DLR-ONERA-cooperation NLAS (Non-Linear Aeroelastic Simulation)
- DLR-ONERA-project: SHANEL (just beginning)
Fluid-Structure-Coupling Using TAU and FEA
CFD/FEA-Interpolation

- **Background:**
  - Physically correct spatial interpolation between CFD and FEA discretization
  - Introduction of interpolation algorithms into TAU code
- **Challenges:**
  - Investigation of suitable coupling algorithms
  - Usage of detailed, large scale models
- **Approach:**
  - Static coupling of FEA (NASTRAN) and CFD (TAU) by file-based communication scheme; use of TAU deformation tool
  - Different interpolation algorithms, for large models: subset interpolation
Fluid-Structure-Coupling Using TAU and FEA
Example - Medium Model Complexity

- fluid and structure with different discretization

**CFD-model**
54,653 surface grid points

resulting load on nodes from calculated aerodynamic pressure?

**FE-model**
75 nodes

deformation of CFD-mesh for given structural deformation?

Research example: AMP-Wing
Fluid-Structure-Coupling Using TAU and FEA
Example - High Model Complexity

Industrial example: A340-300

CFD (half) model
287,620 surface grid points

FE (half) model
29784 nodes
Fluid-Structure-Coupling Using TAU and FEA
Airbus A340-300 – Coupling Structure

- chosen surface nodes of the finite elements structure
- four separate coupling structures with 1131 nodes
**Fluid-Structure-Coupling Using TAU and FEA**

**Test of Subset Interpolation**

- 287620 x 1131 surface nodes
- up to 4.0 m analytical deformation at wing tip
- up to 3.0 m at horizontal tailplane
- Max. difference of the interpolated surface:
  - wing ~1.5 cm
  - pylon ~3.0 cm
  - nacelles ~0.9 cm
  - horizontal tail ~2.9 cm
  - vertical tail ~0.55 cm
  - fuselage ~1.6 cm
Fluid-Structure-Coupling Using TAU and FEA
Static Aeroelastic Coupling Results

- Mach = 0.82; $\alpha = 2.02571^\circ$; cruise condition
- 1 Iteration; Example: comparison of different interpolation algorithms

deformed wing of the FE-model

interpolated aerodynamic surface

![Graphs showing comparison of moment distribution](image-url)
Fluid-Structure-Coupling Using TAU and FEA
Time domain simulation of the transonic flutter boundary

- **Background:**
  - time simulation of the transonic flutter boundary to complement classical approaches typically based on corrected DLM methods

- **Challenges:**
  - physical representation, esp. energy exchange between systems
  - small step size, large amount of data to be exchanged (meshes), i.e. large computational task
  - Euler calculations not suitable for simulation of transonic flutter boundary!

- **Approach:**
  - co-simulation, time-exact solution
  - CFD-FEA coupling using MATLAB (file-based I/O) or TENT/PYTHON
Co-simulation (loose coupling) for fixed communication interval between Tau and structure solver

- CFD time integration: implicit dual-time step, i.e. implicit BDF2 method for physical timestep and explicit 5-stage Runge-Kutta for inner (local) timestep
- Structure time integration: Newmark method / implicit BDF2 method (SODASRT, DASL based)
- CSS is coupling of 1st-order accuracy
Fluid-Structure-Coupling Using TAU and FEA
Dynamic Flutter-Simulation - Transonic Dip

- two cases: $Ma=0.82; \alpha=2.55^\circ$
  
  (1) $p_0=0.8$ bar (stable)  
  
  (2) $p_0=0.9$ bar (flutter boundary)
AMP – Unsteady Coupling Results - TAU-Nastran

- in region $ma=0.6$
  TAU-Euler
- in region $ma=0.82$
  TAU-RANS
Aeroelasticity-Flight Mechanics-Coupling Using TAU

- Background:
  - Coupling of structural mechanics, CFD and flight mechanics
  - (see more in next presentation…)

- Challenges:
  - Coupling of models of substantially different complexity
  - Investigation of suitable coupling schemes, spatial and in time domain for transient motion

- 2 approaches
Aeroelasticity-Flight Mechanics-Coupling Using TAU

1. So-called “Discrete” approach:
   - Structure based on NASTRAN model, linear, full size
   - Non-linear flight mechanics by separate tool (SIMULA of DLR Institute of Flight System Technology)
   - TAU Euler / RaNS calculations for CFD Coupling, point-based interpolation
   - Overall integration and work flow control in TENT
Aeroelasticity-Flight Mechanics-Coupling Using TAU

2. So-called “Modal” approach:

- Based on elastic multibody simulation model, structure from NASTRAN model after modal reduction, interpolation using MpCCI
- Non-linear flight mechanics inside multibody simulation tool
- TAU Euler / RaNS calculations for CFD Coupling, element-based interpolation
- Overall integration and work flow control in MBS tool or TENT
Aeroelasticity-Flight Mechanics-Coupling Using TAU
Example: AeroSUM Delta Wing – MBS / FEA

- AeroSUM model (generic delta wing on sting)
- Simulation of a guided roll maneuver and a free-to-roll maneuver
SikMa Model - guided roll maneuver

- Roll frequency $\phi_x = 5$ Hz; mach = 0.5; $\alpha = 5.0^\circ, 6.0^\circ$ und $9.0^\circ$;
- Comparison of measured and calculated deflections at the nose.
Comparison between rigid and elastic model

angle of incidence $\alpha = 45.0^\circ$, $\Phi_{x,0} = 45.0^\circ$, $ma = 0.5$

SikMa Model - free-to-roll maneuver

Comparison of the Moments $M_x$ and the roll angle $\Phi_x$ for rigid aerodynamic - flight mechanic coupling and elastic aerodynamic - flight mechanic - structural mechanic coupling.

Deltawing (Euler Calculation)
flow conditions:
$Ma = 0.5$, $\Phi_{0} = 45.0^\circ$
angle $\alpha_{\text{airfoil}} = 9.0^\circ$

$\Phi$ - elastic
$M_x$ - elastic
$\Phi$ - rigid
$M_x$ - rigid
Flap deflections by Interpolations - Unsteady Aerodynamic

Mach=0.5; \( \alpha = 0.0^\circ \); antisymmm. flap deflection of 10.0\(^\circ\); flap frequency=5.0 Hz; \( \Delta t=0.002\); 100 time steps per periode
Conclusion:
Commendation and “Wish List”

- Time for thanks and praise:
  - TAU team responsive and helpful
  - TAU shows good functionality of solver and pre-processor in parallel operation
  - Error messages are helpful for users
  - High stability in Euler mode, with meshes of good quality also in Navier/Stokes-Mode
  - Good functionality of deformation tool with Euler meshes
Conclusions: Commendation and “Wish List”

- Suggestions:
  - aeroelastic coupling based on file I/O possible, but cumbersome for time simulation (improvement, e.g. use of PYTHON, is work-in-progress!)
  - partially satisfactory functionality of deformation tool for Navier/Stokes-meshes with large deformations
  - Chimera technique in combination with deformation tool is necessary for many aeroelastic applications, e.g. for large deflections or control surface deflection on elastic wings (SikMa, HighPerFlex)

THANK YOU!