Fluid-Structure Interaction in STAR-CCM+
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What is FSI?

Air Interaction with a Flexible Structure

Solution Time = 0.05 (s)

Wind Speed = 20mph
Turbine Motion with DFBI, not prescribed
Displaying IsoSurface of TVR
Tower effects not included
What is FSI?

Water/Air Interaction with a Structure

Courtesy Germanischer Lloyd

Courtesy CFD Marine
What is FSI?

Vortex Induced Vibration and Galloping

MidSpan Displacement
(L/D=50, D=76mm, t=3.5mm, U=1.2m/s)

Solution Time 0.02 (s)
What is FSI?

Aeroelastic Flutter

Pressure Coefficient

1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
What is FSI?

Hydroplaning

Angle: 4.76558 (deg)

Angle: 0.190623 (deg)
What is FSI?

Gulping

Courtesy Tetra Pak
What is FSI?

Ask 20 engineers “What is FSI?” and you will likely get 20 different answers. There is not simply one approach valid for all FSI problems, so the analyst must be presented with a range of options and choose the most suitable.
The Unique Challenges of FSI Simulations

- Protocols and formats for exchanging data
  - Getting data from Code A to Code B
- Mapping data between non-conformal meshes
  - Finding neighbors and interpolating
- Coupling methods
  - Algorithms for accuracy, stability, efficiency
- Dynamic fluid mesh evolution
  - Topology changes in the fluid domain
- Validation of FSI results
Enabling technologies to meet the challenges

- VOF for free surface transient flow
- Overset meshes for motion and deformation
- Fluid interaction with
  - multi-body rigid structures
  - compliant structures
- Co-Simulation between different CAE codes
- Mapping between non-conformal meshes
- Parallel scalability on compute cluster
Simulation of Store Separation

- DFBI – Fluid interaction with a Rigid Body
- Overset Technology
Simulation of Lifeboat Launching

- VOF for free surface transient flow
- DFBI – Fluid interaction with a Rigid Body
- Overset Technology

Overset grids allow simulation of launching of various devices (lifeboats, missiles etc.).
The Challenges of FSI

MAPPING
The 3 steps of “Mapping”

🔍 Searching for opposing neighbors
  – Most of the computer time

🔍 Interpolating source stencil data on a target point
  – Source and targets may be face or vertex

🔍 Often requires integration (quadratures)
  – intensive ➔ extensive variables
  – pressure ➔ force
  – heat flux ➔ heat
  – FEA nodal loads: integration of intensive variables against the shape function.
Neighbor Search Imperative

Search requires little user intervention

The search excludes potential neighbors based on proximity and orientation

Critically important for sheet metal parts

– resolve ambiguities of poor geometry
– thin solid parts may be on the wrong side of the fluid surface

Parallel Mapping is a must!

– Takes advantage of distributed memory

Courtesy of Daimler
Mapping Displacement for Low Y+ meshes

$C_0$ continuous mapping very important for low y+ meshes

Otherwise very easy for morpher to invert high aspect ratio cells in prism layer
Inconsistent Geometric Representations

FEA VIEW of a WING

Shells (no mass, stiffness)

Beam to Surface Mapping

CFD VIEW of a WING
The Challenges of FSI

DATA EXCHANGE
Methods for Exchanging Data STAR-CCM+/CAE

File Based Transfer: Import/Map/Export
- Data exchange via files on a hard-disk
- CAE code need not be resident in memory
- Often called “Loose Coupling”
- User responsible for exchange synchronization

Socket Based Transfer: Co-Simulation API
- API controls exchange synchronization
- Data exchanged via sockets
- CAE code and STAR-CCM+ both executing in memory
  - STAR-CCM+ to STAR-CCM+ Co-simulation
  - STAR-CCM+ to 1D external Codes
    - GT Power, Wave, Olga, AMESim, Relap5
  - STAR-CCM+ to Abaqus Co-Simulation using Abaqus API
STAR-CCM+ : Loosely Coupled CAE Support

**Import CAE Mesh:** import from/export to the native CAE format
- Abaqus, Nastran, Ansys, STAR-CCM+
- RadTherm, es-ice

**Map & Export Results to CAE**
- Surface Loads
  - Pressure, Shear Traction
  - Heat flux or Temperature
  - Heat Transfer Coeff, Ambient Temp
- Volume Loads
  - Temperature
  - Heat Source

**Import & Map FEA Results**
- Temperature → Fluid Wall BC
- Displacement, Eigenmodes → Morpher
STAR-CCM+ can provide an import/map/export service as a powerful complement to HEEDS
Abaqus/STAR-CCM+ Co-Simulation

Coupling via Abaqus Co-Simulation API of SIMULIA
- Manages Coupling Synchronization/Exchange/Mapping
- Abaqus v6.13/STAR-CCM+ v8.04+ (implicit coupling)
- Surface to Surface Mapping

STAR-CCM+ → Abaqus (explicit or standard)  
- Pressure 
- Shear traction 
- Surface HTC, Tref

Abaqus → STAR-CCM+
- Displacement, velocity 
- Temperature

Ball and Socket Stop Valve

Hydroplaning
Flexible riser (L/D = 50) in turbulent crossflow.

**Strategy:** Couple STAR-CCM+ to Abaqus
- Implicit Coupled on workstation

**STAR-CCM+ Vortex Induced Flow around Flexible Pipe**

**Abaqus FEA for Flexible Pipe**

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**Riser cross section**

Riser dimensions:
- L = 3.8125 m,
- D = 76.25 mm
- T = 7.05 mm

**Current:**
- Vin = 1.2 m/s
- Re(D) = 81700

**Structural Material Properties:**
- Young’s Modulus = 1.5 GPa;
- Poisson ratio = 0.42;
- density = 8563 kg/m³;
Coupled Solution: Displacement and Vorticity

Solution Time 0.02 (s)

z/L=0.25

z/L=0.5
The Challenges of FSI

Coupling Technique
Degrees of Coupling

Two-way coupling for fluid-elastic equilibrium
- Steady-state flow over static structure deformed by fluid loads

One-way dynamic coupling
- Loads only go from fluid to structure
- Loads only go from structure to fluid

Two-way dynamic coupling
- Explicit (exchange loads once per time step)
  - Unstable for relatively light and/or compliant structure interacting with heavy, incompressible fluid
  - Interest in physics with time scales which are long compared to acoustic time scales
- Implicit (exchange loads more than once per time step)
The Challenges of FSI

Validations
Experimental Validation: Wedge Drop In Water

 différencier

Comparison of Experiments and Models

Peterson, Wyman, and Frank: “Drop Tests to Support Water-Impact and Planing Boat Dynamics Theory”, Dahlgren Division Naval Surface Warfare Center, CSS/TR-97/25

STAR-CCM+ VOF with different bodies
- Rigid Body (6DOF, DFBI)
- Elastic Body (FV stress)
- Elastic Body (Abaqus Co-Simulation)
- Elastic Body (FE Stress)
Wedge Drop In Water

(ii; ts; md fluid/solid):
FSI FV: 50; 1e-4s; 97.3k cells/7.7k cells
FSI Co-sim: 10; 1e-4s; 97.3k cells/1k els

All Methods give good agreement to experiments
AeroElastic Prediction Workshop: HIRENASD

2.3M cells

53K nodes
Aerodynamic Equilibrium at different AOA

- Static Structure, Steady airflow at deformed shape
- $Ma=0.8$, $Re=23.5 \times 10^6$, $q/E=0.48 \times 10^{-6}$

![Graphs showing Lift Coefficient and Wing Tip Displacement vs. Angle of Attack](image-url)
Windoff Vibration Modes: Abaqus vs Experiment

- \( f = 25.55 \text{ Hz} \) (26.25)
- \( f = 80.25 \text{ Hz} \) (78.20)
- \( f = 106.20 \text{ Hz} \)
- \( f = 160.35 \text{ Hz} \) (165.25)
Aeroelastic Equilibrium Cp: AOA 2°
Aeroelastic Equilibrium $C_p$: AOA 2°, near wing tip

![Diagram](image_url)
Fluid-Elastic Instabilities in a Tube Bundle

Fluid-Elastic Instabilities in a Tube Bundle

Vorticity

Vu=0.25m/s

Vu=0.31m/s
Future Developments in STAR-CCM+

- STAR-CCM+ Development Directions
  - Introduce and couple more physics within STAR-CCM+
  - Allow for co-simulation with a multiple of CAE solvers

- FEA Models Introduced
  - 3D continuum, shells, and beams

Solution Time 0.002 (s)

Solution Time 0.03 (s)
Many FSI challenges

Demonstrated industrial “strength” examples of STAR-CCM+

The key enablers of the technology are
- VOF for free surface transient flow
- Overset Technology for motion and deformation
- Fluid interaction with
  - multi-body rigid structures
  - deforming structures
- Mapping between non-conformal meshes
- Co-Simulation Application Program Interface
- Parallel scalability on compute clusters

Conclusions
Thank You For Your Attention