BOUNDARY ELEMENT (BEM) BASED FLUID STRUCTURE INTERACTION: CONCEPTS IN LINFLOW compared to COUPLED NAVIER-STOKES and STRUCTURAL SOLVERS FOR FSI

The concepts for Fluid Structure Interaction ("FSI") in LINFLOW are unique and computationally extremely efficient for some very important classes of "real world" applications compared to the concept of coupling Navier-Stokes and Structural FE- Solvers. The concepts applied in LINFLOW are very well suited for FSI in connection with vibrations (e.g. acoustics due to flow induced vibrations, fluid induced vibrations of pipes including "singing risers", flutter of aircraft wings and car spoilers, ship propeller dynamics) as well as for structural stability evaluation and FSI induced fatique. On the other hand, the coupled CFD - Structural Solver concept is better suited than those in LINFLOW for other types of engineering problems. These types include problems where viscous effects play a major role, where large structural displacements interact with the flow, where no rapid oscillating movements occur, and applications where heat transfer effects are significant. Following is a brief comparison of the two concepts.

Before doing the comparison, we will discuss how one would utilize LINFLOW as an engineering tool.

LINFLOW has been developed to give the engineer insight into the characteristics of a aeroelastic or fluid-elastic system. To fully appreciate the concept, you should be familiar with structural dynamic analysis (what you anyhow have to be if you want to solve Fluid-Structure Interaction problems).

There is a strong similarity between the way one addresses a transient problem in structural dynamics and a Fluid-Structure Interaction problem. In strutural dynamics generally, and in heavy non-linear dynamics in particular, one should always perform a structural eigenvalue analysis and a harmonic response analysis prior to any transient analysis. The (structural) eigenvalue analysis will provide a wealth of information about model (e.g. about discretization, boundary conditions) and the system to be simulated. If a non-linear transient structural analysis is to be performed, one is well advised to perform a linear transient analysis to begin with in order to get an impression of how the system reacts to the (time-dependent) exitations.

With the modal approach to FSI problems in LINFLOW (hereinafter "LF"), the relevance of comparing eigenvalue analysis and transient linear analysis in structural analysis becomes clear:

- Firstly, an eigenvalue analysis of the structure that couples with the fluid has to be performed since LF needs the information contained in the eigenfrequencies, the corresponding eigenmodes, and the modal load vector.
- The first analysis one performs in LINFLOW, is an eigenvalue analysis , utilizing the results from the structural eigenvalue analysis.
- A subsequent analysis will typically be a harmonic analysis.

Some of the information that can be obtained from a LF eigenvalue analysis is:

- Eigenfrequencies of the coupled fluid-structure system as a function of the velocity, pressure and the properties of the medium.
- The stability characteristics of the system (i.e. whether there is a likelihood of flutter or not).
- The (participation) factors of the structural modes coupling with the fluid.

With this information, one can:

- Decide what coupled aero-/fluid- elastic modes are critical for flutter.
- Study the influence of structural stiffness changes.
- Study the effects of geometry changes.
- Decide whether there is a need for further analyses by a coupled Navier-Stokes / Structural Solver.

A (transient) harmonic analysis can be utilized to determine Aero-elastic or Fluid-elastic effects like

- Hydrodynamic added mass (This is already available when performing the fluid-elastic eigenvalue analysis)
- Acoustic radiation damping
- Aerodynamic (or fluid dynamic) damping (due to phase shift between the motion of fluid-elastic coupled dynamics and the pressure generated by the motion)

So, summing up, we can say that LINFLOW is conceptually for FSI what a linear program is for structural analysis.

Now to the comparison between LINFLOW and a Navier-Stokes Solver coupled with a Structural Analysis program for FSI.

Fluid Dynamics

The Navier-Stokes Solver

- Volume grid used for space discretization.
- Time domain solutions for unsteady flow problems.
- A broad rang of features (e.g. turbulence models, heat transport)
- Will solve for local rotational and viscous flow.

LINFLOW Fluid Dynamics:

- Linearized fluid dynamics, assuming inviscid and locally irrotational flow. Global circulation treated with wake models.
- Boundary Element Method used for space discretization (this makes model generation much easier, since a mesh of the flow domain is not needed).
- Frequency domain solution for unsteady flow problems (when the steady flow velocity is zero the solution gives a pure acoustic solution).

Fluid-Structure Interaction

Coupled Navier-Stokes and Structural Solvers

- A time domain solution of the FSI problem using ALE based fluid dynamics.
- Sequential information transfer between the physics environments.

LINFLOW Aero-/Fluid-elastics

- A frequency domain solution of the so called Aeroelastic (or fluid-elastic) equation of motion system. LINFLOW solves an equation system that accounts for the structural dynamics as well as the fluid dynamics. Uses eigenvalues, eigenvectors, and modal load vectors from a structural analysis program for the description of the structural dynamics.
- Solves the aero-/fluid-elastic equation of motion as a non-linear eigenvalue problem for stability analysis. This enables prediction of flutter type problems in the system envelope (envelope described by flow velocity range, pressure level range, temperature range etc).
- Full Harmonic and Spectrum analysis capabilities, through the solution of the aero-/fluid-elastic equation of motion as frequency domain response problem.
- Transient analysis capabilities, using the efficient frequency domain description of the aero-/fluid-elastic system (under development).

As can be seen from the above, the LINFLOW concept for FSI differes radically from the concept of coupling a Navier-Stokes solver with a Structural analysis program. The LINFLOW concept addresses the interaction between a fluid (moving or at rest) and a vibrating structure, an interaction that can not easily be studied by any other software.