ANSYS

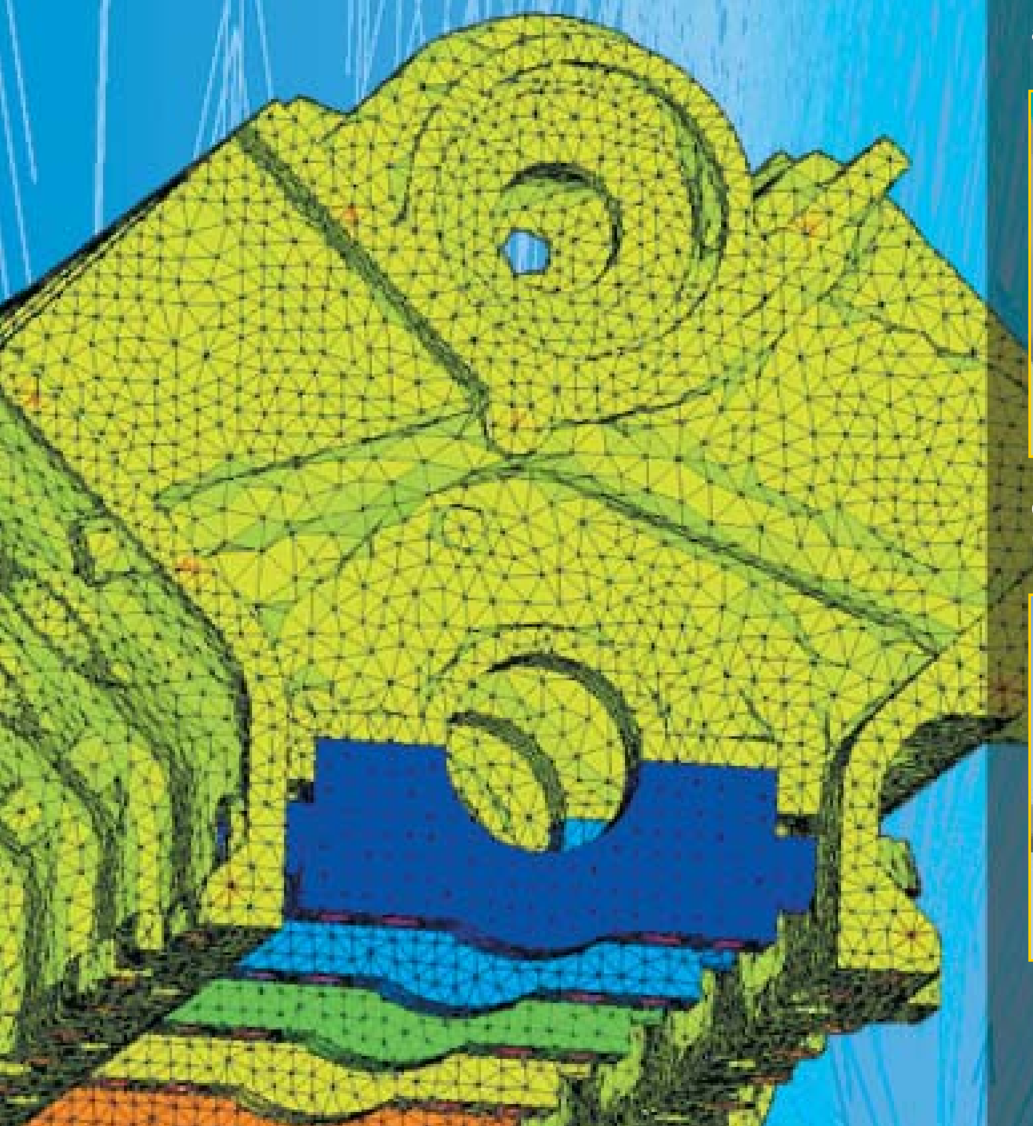
SOLUTIONS™

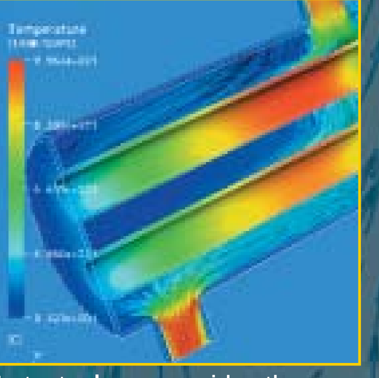
THE PREMIER MAGAZINE FOR DESIGN INNOVATION™

FALL 2005

Industry Spotlight:

Shortening Automotive Development Time





Latest release provides the industry's most advanced and flexible FSI solution.

Designers perform analysis early to shorten the development cycle.

Platform provides an integrated multi-disciplinary work environment.

Advances in Fluid Structure Interaction Technology

Latest release provides the industry's most advanced and flexible FSI solution.

By Dr. Paul Lethbridge
Multiphysics Product Manager
ANSYS, Inc.

Applications where deformation of a solid structure perturbs the flow of a fluid in proximity to the solid can be generally described as fluid structure interaction (often referred to as FSI). The deformation of the solid may be the result of the initial fluid pressure load, or it may be produced by thermal stress or even electro-magnetic forces.

The effects of FSI are around us in many everyday situations. It is fundamental to the function of aircraft, for example, where the lift and drag forces created by the structure moving through the air causes the structure to move up, down, left or right. Consider inflating a toy balloon, which expands and deforms with the increasing fluid volume and pressure. The vibration and noise of an automobile side window or sunroof when partially open is another example. FSI also plays a critical role in many biomedical systems, such as elastic blood vessels deforming as blood pulses through them.

The interaction (or coupling) between the structural and fluid physics of FSI can be either unidirectional or bidirectional. Unidirectional coupling is useful for applications where the structural deformation is small but the stress created from the deforming fluid load (pressure or temperature) is important, as in many gas turbines.

As shown in Figure 1, the physics are decoupled from feedback in unidirectional coupling – either the pressure from the fluid solution is passed one time to the structural solver as an additional load, or the structural deformation is passed one time to the fluid solver so that the fluid domain can be updated.

An example of bidirectional coupling is when an oscillation is produced in the structure. The oscillation may be damped or undamped. In the damped case, the structure may simply reach an equilibrium position. In undamped cases, catastrophic failure of the structure may occur, as exhibited in the 1940 Tacoma Narrows bridge collapse in Washington state, USA, where high winds created undamped oscillations of the span.

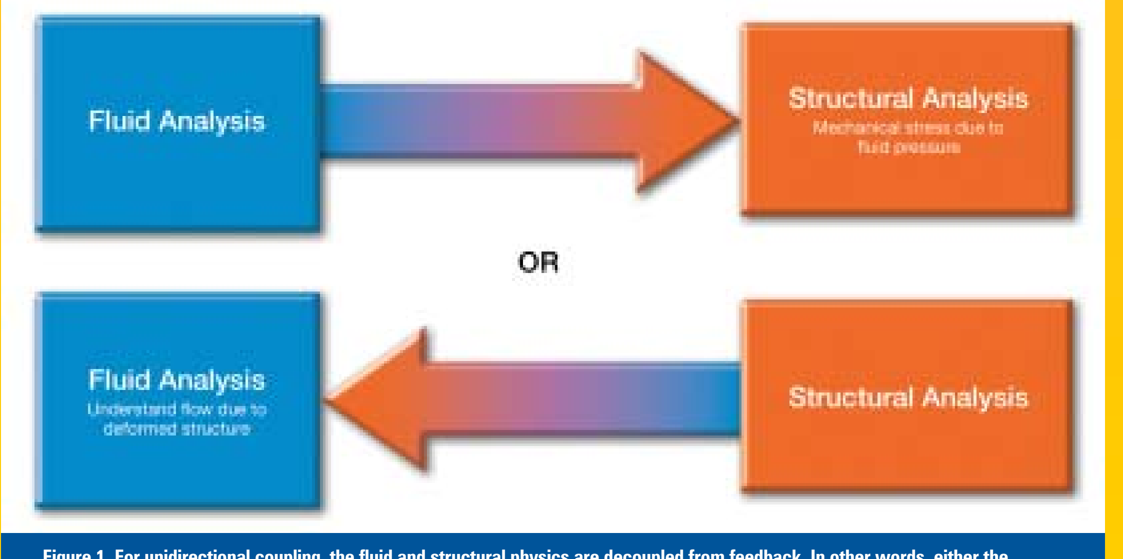


Figure 1. For unidirectional coupling, the fluid and structural physics are decoupled from feedback. In other words, either the analysis will include the fluid pressure deforming the structure (but excludes any effect that the deformed structure has on the fluid flow) or the analysis will include the deformed structure's effect on the fluid flow but will exclude the fluid pressure acting on the structure.

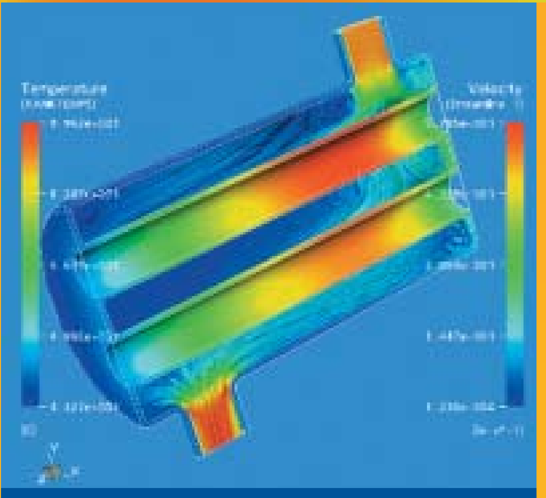


Figure 2. Conjugate heat transfer (CHT) analysis of a heat exchanger determines the fluid flow and heat transfer between the fluid and structure. Image shows the resultant temperature distribution and fluid velocity streamlines.

Although unidirectional coupling has important applications, what most people imply when discussing FSI is bidirectional coupling, when the interaction between both physics is fully realized. Bidirectional analyses are far more computationally expensive than unidirectional, since both physics are being solved iteratively. Results are passed as loads between the two physics at each iteration, and the solver is managing both physics analysis databases simultaneously. Conversely, unidirectional coupling, although sequential, is not iterative. Loads are passed once, in one direction. For example, a user can solve for the fluid physics, save the results to a file and then read the fluid pressure results as loads into a subsequent structural analysis. This unidirectional "load passing" doesn't even need to happen on the same day! The ANSYS FSI solution provides both bidirectional and unidirectional FSI coupling.

Factoring in Heat Transfer and Other Physics

In many FSI applications, heat transfer is an important consideration since temperature can drastically affect both the fluid and the structure. For the structure, differential thermal expansion/contraction results in thermal stress, possibly leading to additional deformation of the structure and further flow interaction. For the fluid, viscosity varies significantly with temperature. There are many other material properties that are also temperature-dependent and need to be considered if accurate solutions are desired.

The simultaneous solution of fluid flow and heat transfer between the fluid and structure is often referred to as conjugate heat transfer (CHT), although CHT typically does not include any thermal-stress capability. The ANSYS FSI solution incorporates both CHT and thermal stress, allowing a user to capture the primary effects of heat transfer in both the fluid and the structural analysis, if required. (Although one could argue that coupling the heat transfer between the fluid and the structure is a type of FSI, the CHT terminology predates FSI and is most commonly used.) The ANSYS FSI solution is also flexible enough to allow a user to choose any permutation of fluid, solid and thermal effects to be incorporated into the analysis, for example. A very common analysis is CHT with unidirectional thermal stress. An example of CHT analysis of a heat exchanger is shown in Figure 2, and Figure 3 depicts bidirectional coupled FSI with CHT and thermal stress.

The ANSYS Multiphysics solution additionally allows users to factor in many other physics into the FSI analysis such as electromagnetic-fluid structure useful in magneto-rheologic (MR) fluid applications. MR fluids have a shear stress that is a function of magnetic field. Common applications are automotive shock absorbers with electrically variable damping rates. Read the Multiphysics article published in the Fall 2004 issue of *ANSYS Solutions* for more information on other coupled physics applications.

The Multi-field Solver

In 2003, ANSYS, Inc. launched the Multi-field solver. This technology provides an easy-to-use framework to solve coupled field problems in many new markets and applications where previously solutions have not existed. The Multi-field solver is a general-purpose,

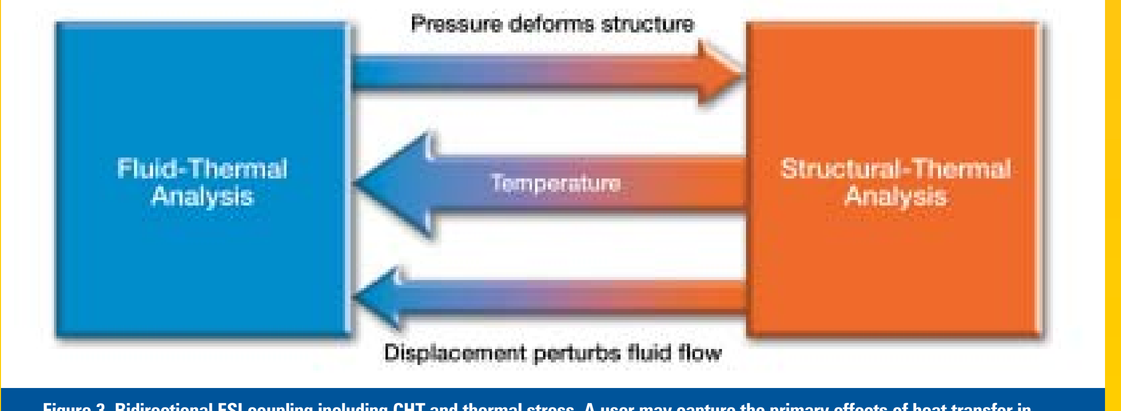


Figure 3. Bidirectional FSI coupling including CHT and thermal stress. A user may capture the primary effects of heat transfer in both the fluid and structural fields of the FSI analysis.

Figure 4. In this FSI analysis of blood flowing in an elastic artery, the fluid pulse travels from top to bottom of the artery, deforming the structure as it passes through.

automated sequential coupled physics solver applicable across all physics available in the ANSYS Multiphysics solution, including CFX fluid dynamics and FSI. It is interesting to note that the original Multi-field solver was actually an evolution of the FLOTRAN-based FSI specific solver.

The ANSYS Multi-field solver has supported unidirectional coupling with CFX since release 8.0 in 2003, and it has been enhanced at release 10.0 to support coupling with CFX for bidirectional FSI applications. The structural part of the analysis is solved using ANSYS Multiphysics (or ANSYS Mechanical) and the fluid part using the CFX full capability solver. The enhanced Multi-field solver technology (called MFX-Multiple code) allows the structural and fluid solutions to run simultaneously on the same or different machines. This distributed Multi-field capability can accommodate much larger models more efficiently than a Multi-field solver using a single machine environment.

- Unidirectional coupling is available between structural, thermal, electromagnetic and fluids physics and is suitable for steady-state analysis.
- Bidirectional coupling is available between structural, thermal and fluid physics for time-transient or steady-state analysis with moving and/or deforming geometry.

The underlying numerical method employed in both unidirectional and bidirectional FSI coupling is, strictly speaking, load vector coupling. That is, the fluid and structural physics are coupled by passing loads across physics field interfaces, and each physics field maintains its own mesh and degree of freedom set associated with its physics. Bidirectional coupling is iterative, whereas unidirectional coupling is not.

The MFX-Multiple code coupling is based on proprietary inter-process communication technology. This technology ensures that the CFX solver can be run in parallel using any of its built-in parallel communication methods without any interference or conflict with the FSI coupling. This means that not only can the fluid and structural computation be run on different machines, but also that any number of computers can be applied to reduce the elapsed time of the fluid portion of the FSI analysis. For the structural portion of the FSI analysis, a user may incorporate many of the advanced features of ANSYS Mechanical, such as material and structural non-linearities. Further, the MFX-Multiple code solver can communicate across a local area network, a wide area network or even via an Internet connection.

FSI Analysis in Action

One of the most important and challenging application areas of FSI is biomedical, where engineers study the

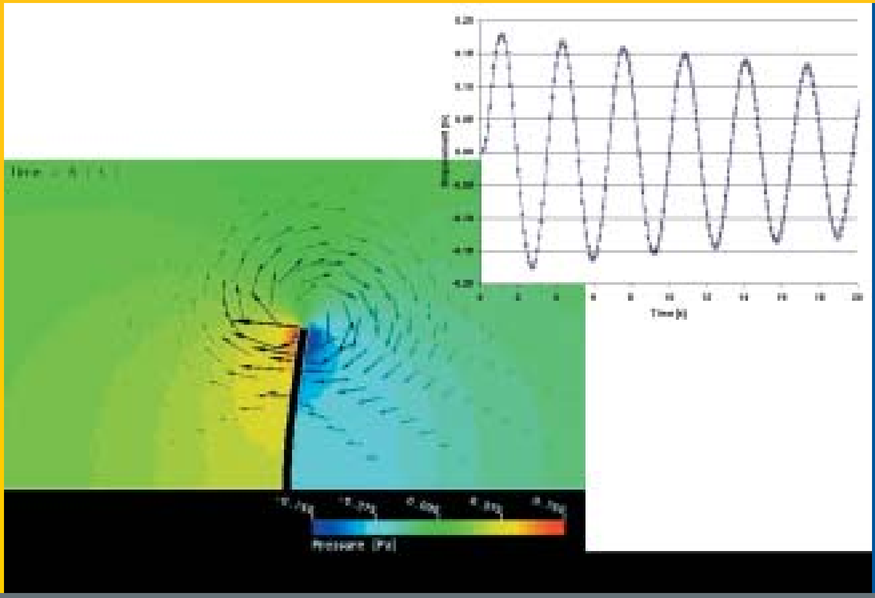


Figure 5. Civil engineering applications use FSI analysis in cases such as this study of a wall subjected to a wind load. Inset shows the time history of the displacement of the top of the wall.

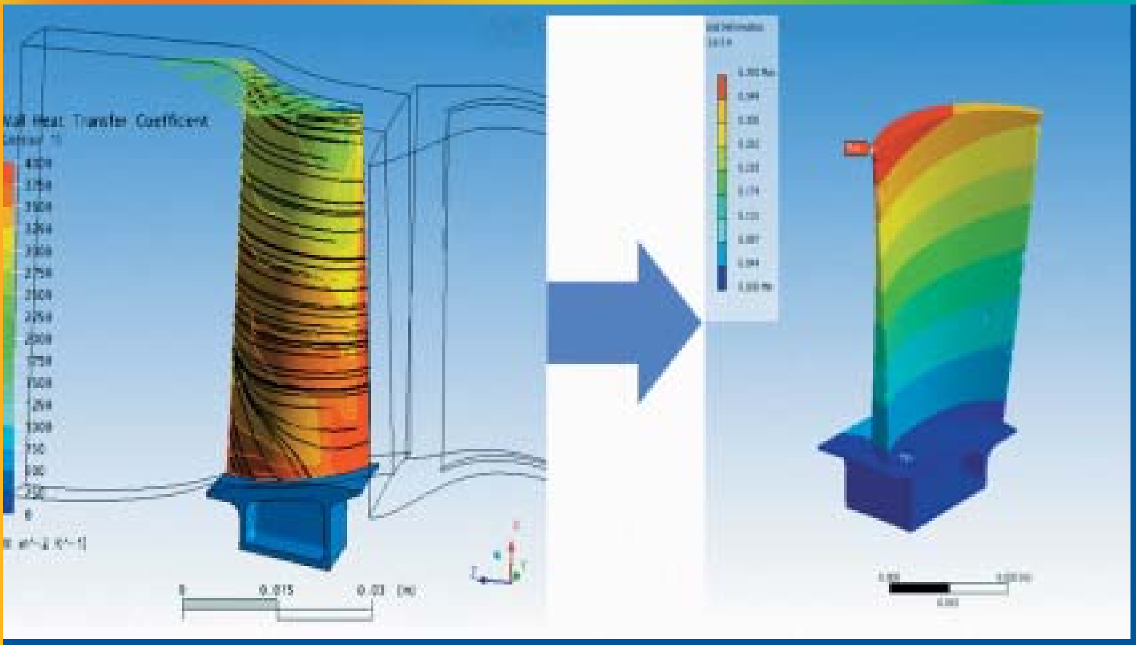


Figure 6. FSI analysis of a gas turbine blade computed stress and deformation resulting from fluid pressure and temperature plus additional loads due to rotation and other thermal loads.

impact of stent grafts on blood flow, for example, or the efficiency of inhalers for aerosol drug distribution into the lungs. The sequence of models in Figure 4 shows an FSI analysis of blood flowing in an elastic artery. The analysis was performed with ANSYS Mechanical coupled with ANSYS CFX full capability solver.

A particular challenge in biomedical FSI analysis is that structures are often very elastic (body tissue), and fluids have complex behavior (non-Newtonian in the case of blood). The ability to incorporate highly nonlinear material attributes into the FSI analysis is a key feature of the ANSYS FSI solution.

Civil engineering structures must undergo vigorous testing and approval. As architectural and materials technology advances, the ability to accurately predict a structure's performance to expected wind loading at the design stage is critical. FEA has long been accepted as a standard tool for structural analysis, and the availability of FSI enhances the virtual prototype capabilities of ANSYS products for this industry. Figure 5 shows the analysis of a wall subjected to a wind load, performed with ANSYS Mechanical coupling with ANSYS CFX full capability solver.

As discussed earlier, unidirectional coupling FSI has applications in situations where structural deformation does not appreciably impact the fluid flow, but structural stress due to fluid pressure is significant. The most common industry applications for this type of FSI are gas turbines and some fluid handling devices. Figure 6 shows a unidirectional FSI analysis of a gas turbine blade. In this analysis, fluid pressure and temperature are passed unidirectionally as loads into a structural analysis where they are combined with additional mechanical loads due to the structure's rotation and other thermal loads. The resultant stress and deformation are then computed. This analysis used the MFIMPORT feature of ANSYS Multiphysics coupling with CFX full capability solver. ■

FSI Capability Summary

Benefits

- Supplied and supported by a single vendor without third-party coupling scheme needed
- Reduced solution deployment cost due to fewer analysis software tools to purchase, learn and manage
- Large FSI problem sizes can be addressed by distributing the solution across two machines.
- CFX solution may make use of parallel processing (requires additional CFX parallel modules).
- Implicit coupling provides rapid and robust convergence, which means less time and effort to complete analysis.
- FSI physics coupling can make use of LAN, WAN or Internet connection.

Key Features

- Multi-field solver-based
- Bidirectional and unidirectional coupling:
  - Conjugate heat transfer (CHT)
  - Fluid structure
  - Fluid structure with CHT & thermal stress
- Surface- and volume-based load transfer:
  - Pressure
  - Force
  - Displacements
  - Temperature
  - Heat flux
- Mesh interpolation schemes:
  - Non-conservative
  - Conservative
- Applications:
  - Steady-state analysis
  - Time-transient analysis
  - Fixed geometry
  - Moving and deforming geometry