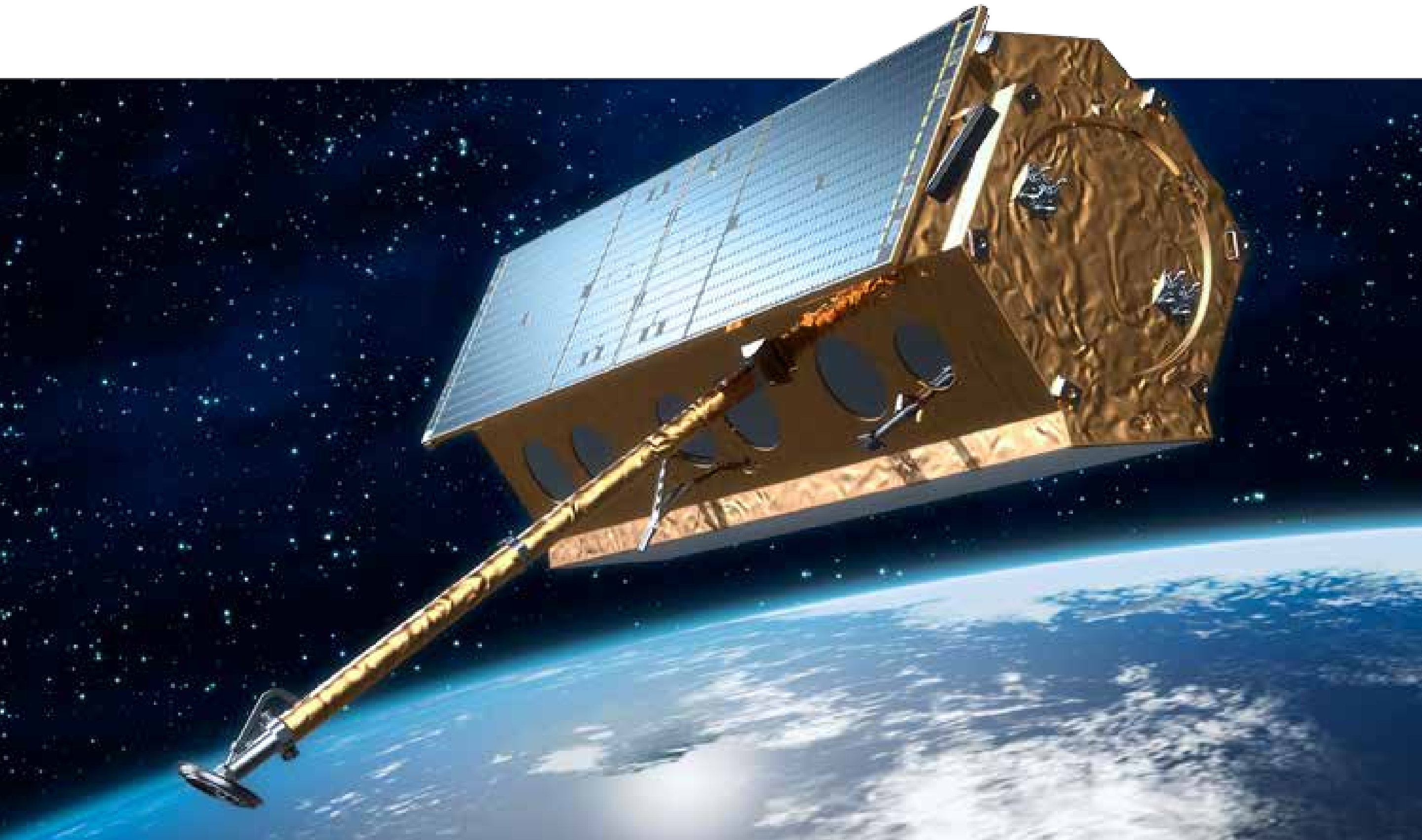

Decreasing Spacecraft Fuel Sloshing

Fuel sloshing in the tank of a spacecraft has the potential to change the center of mass. This affects the carefully calculated maneuvers that accurately direct sensors to specific ground locations. Airbus engineers used fluid–structure interaction simulation to evaluate the ability of a proposed elastomeric membrane to minimize the effect of fuel sloshing on the center of mass in the early stages of developing a spacecraft.

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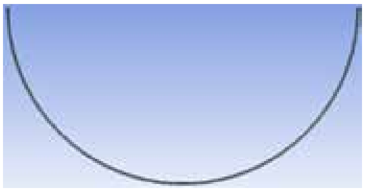
Typical missions of spacecraft include monitoring the weather and the environment — such as changes in vegetation, atmospheric gases, ocean conditions and ice fields — and performing terrain mapping. Airbus Defence and Space is a recognized leader in this field, providing complete solutions to increase security; boost agricultural performance; maximize oil, gas and mining operations; improve management of natural resources; and protect the environment by monitoring deforestation and carbon emissions.



Drawing of the membrane at an offset from the lower part of the tank

Attitude control is particularly important because spacecraft are often tasked with observing a specific fixed point on the ground. Their attitude is changed frequently to observe a different location or to point an antenna

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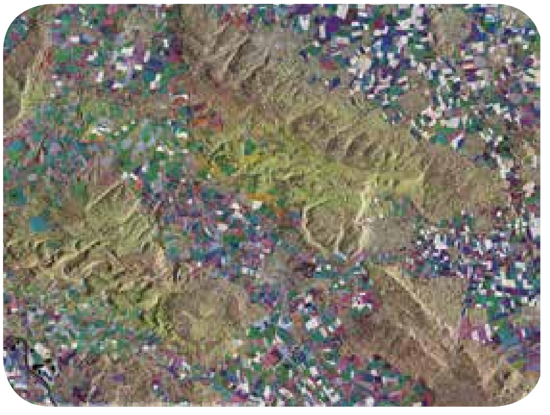


Typical image captured by Airbus spacecraft

toward a ground station to transmit the collected data. The attitude control system (ACS) typically relies on control moment gyroscopes and reaction wheels to perform smaller attitude maneuvers using electricity provided by solar arrays. Thrusters fueled by propellant perform larger maneuvers. The algorithm used for the control moment gyroscopes and reaction wheels requires precise knowledge of the center of mass of the spacecraft. But as it begins to move, liquid fuel sloshes around in its tank, changing the center of mass and generating forces on the tank wall that counteract the control moment gyroscope or reaction wheel.

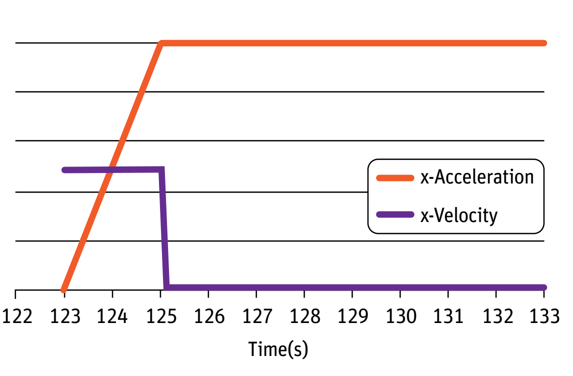
Spacecraft often use remediation measures to reduce sloshing so that the spacecraft can be controlled within the allowable attitude window. One approach is to use physical barriers, such as baffles or compartments, to control sloshing. Another common method is to use an elastomeric membrane to divide the tank into two compartments — one filled with fuel and the other with pressurized gas — to dampen sloshing.

Designers must determine whether remediation is needed to achieve attitude control specifications and, if so, to identify an approach that will meet the specifications with the lowest cost and weight penalty. Physical experiments are almost impossible to use to measure sloshing in zero gravity and would be very expensive. Airbus engineers decided to use simulation early in the design process to evaluate the performance that could be achieved by an elastomeric membrane, because making design changes early is less costly than making them later.

Modeling sloshing under the influence of an elastomeric membrane is complicated because of the complex interactions of both the liquid fuel in the tank and the membrane. Airbus engineers had never modeled these interactions before, and a literature search did not identify any published results that could act as a guide. So the engineers decided to take advantage of the integration of ANSYS multiphysics tools in the ANSYS Workbench environment to perform fluid–structure interaction (FSI) simulations to analyze the behavior of the proposed membrane.

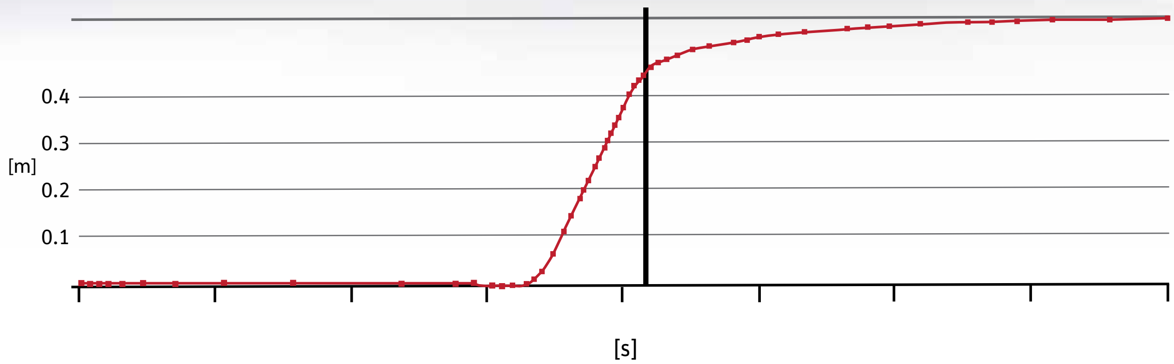
Design Study for a Spacecraft

Airbus engineers needed to perform a design study to calculate the impact of a membrane on the response of a spacecraft under development. They were asked to estimate the changes in the center of mass and the forces exerted by the fuel on the tank walls as the spacecraft made several defined maneuvers. This required simultaneously solving for the effect of the liquid fuel on the membrane and the influence of the membrane on the fluid. The biggest obstacle in



Typical translation profile applied during FSI simulation

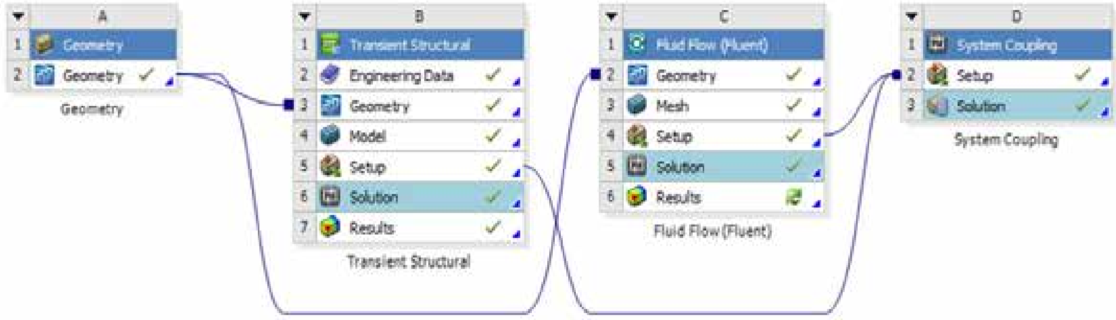
> *"FSI and other multiphysics simulations enable Airbus engineers to make more informed design decisions at a stage in the design process when it is possible to have a substantial impact."*



Displacement of the midpoint of the membrane during the mechanical deformation process

performing FSI simulations is that the computational fluid dynamics (CFD) software used to simulate the fluid and the finite element analysis (FEA) software used to simulate the membrane are often supplied by different vendors and are not designed to work together. The user must find a way to integrate these tools. This may involve writing and validating scripts, and transferring data manually between CFD and FEA software packages for each simulation run. Manual intervention in the simulation process takes time, results in a complex simulation workflow and can sacrifice the accuracy of the overall simulation.

ANSYS software overcomes these difficulties by providing the complete physics required for FSI simulation, including CFD and FEA solvers, integrated in the ANSYS Workbench environment. The output from one software package is coupled as input to the next with a simple drag-and-drop operation, so there is no need for manual data transfer. In this case, Airbus engineers modeled the membrane as a solid offset from the lower part of the tank and created a fluid outlet on the lower tank wall. The unique integration between ANSYS Fluent and ANSYS Mechanical made it possible to use the solid part of the tank walls to contain the fluid domain model and the surfaces to define ANSYS Mechanical solid elements. The tank walls were also included in the ANSYS Mechanical model to impose contact with the

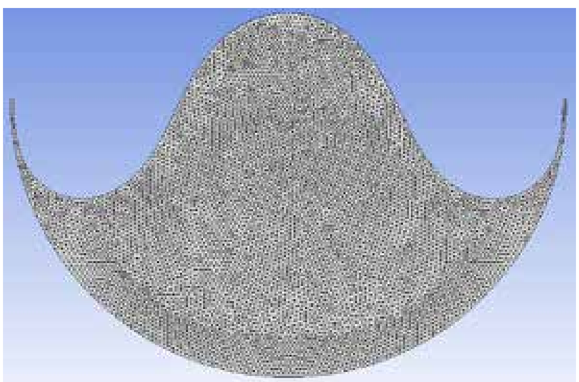


Airbus engineers linked fluid and structural codes by dragging the output of one code to the input of another.

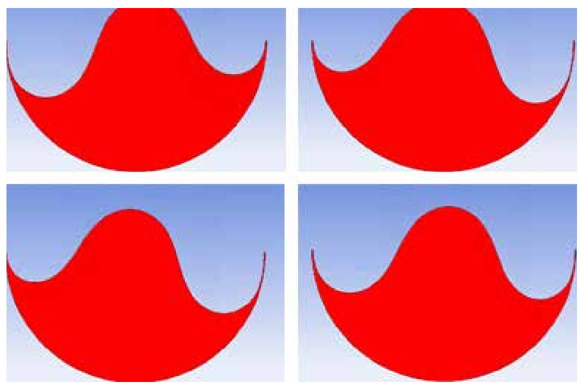
"ANSYS software provides the complete physics required for FSI simulation, including CFD and FEA solvers integrated in the ANSYS Workbench environment."

membrane. The entire model was only one element thick to reduce computational effort so it was in effect a 2-D simulation.

Filling the tank could have been done with FSI, but instead Airbus engineers used the simpler and less computationally intensive approach of applying mechanical pressure rather than fluid pressure to deform the membrane toward the upper part of the tank. The deformed shape was then applied to the fluid model. A mass flow outlet was added, and the tank was allowed to drain to the desired filling ratio while maintaining equilibrium between the fluid pressure and stress in the membrane. A flow rate profile was used to drain the tank gradually to avoid generating pressure waves.



Stabilized position of membrane after tank drained to partial level



FSI results

Performing Fluid–Structure Interaction Simulation

Once the shape of the membrane and its associated stress field were determined, engineers applied specified translation profiles to the tank. Each profile consisted of an acceleration time history representing a typical spacecraft maneuver. At each time step in the transient FSI simulation, ANSYS Fluent calculated the fluid reaction forces. These forces were seamlessly transferred by ANSYS Workbench to the ANSYS Mechanical solver to load the elastomeric membrane. ANSYS Mechanical then calculated the deflection of the membrane. The updated membrane shape was passed back to ANSYS Fluent, which used it to establish the flow domain for the next simulation time step. The simulation results included the center of mass of the tank and the forces and torques exerted by the fluid on the tank walls at each time step.

Airbus engineers used FSI simulation in the early stages of the design process to model the behavior of the elastomeric membrane subjected to a typical spacecraft maneuver. They also use simulation to evaluate other sloshing remediation methods such as baffles or compartments. The final aim is to determine which solution is the more suitable for tank design.

With ANSYS software, Airbus engineers developed a new capability: They are now able to simulate a tank configuration with an elastomeric membrane. FSI and other multiphysics simulations enable Airbus engineers to make more informed design decisions at a stage in the design process when it is possible to have a substantial impact on the performance, cost and lead time of the finished product.

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