SESP 2010

Session:	Session: Modelling Simulation (18)
Type:	Concurrent Session
Date:	Thursday, September 30, 2010
Time:	09:00 - 10:30
Room:	Newton
Chair:	
Co-chair:	
Remarks:	

Seq	Time	Title	Abs No
1	09:00	Strong Coupling Algorithm to solve Fluid-Structure-Interaction Problems with a Staggered Approach	

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During the last decades, numerical analysis of multi-physics problems has been increasingly used, especially for space applications. A particularly challenging problem is the fluid-structure interaction (FSI), where a fluid flow (liquid or gas) induces forces and thermal fluxes on a solid structure, which modifies in return the fluid domain, the velocities and the temperature fields at the fluid-structure interfaces. The ESA Flow-SCHyp research project, started in 2006, is dedicated to the resolution of FSI couplings.

To solve an FSI problem, two different approaches can be used: the monolithic one, where a single solver is in charge of the resolution of the complete system of equations. The second one is the staggered one, where two solvers deal respectively with the fluid and the structure equations, and exchange information at the interfaces to ensure continuity of the variables (velocity and temperature) and compatibility of the charges (forces and heat fluxes). This second approach has been developed in the Flow-SCHyp project, as the CSM (Computational Structure Mechanics) solver Oofelie®, developed at Open Engineering, has been coupled with the CFD (Computational Fluid Dynamics) solver FINE™/Hexa, developed at Numeca International. The exchange of information at the interfaces is done using the MPI (Message Passing Interface) protocol.

The main advantage of such a staggered approach is that optimized existing solvers can be reused and coupled. The structure solver uses here a finite element method with second order elements and a second order time-accurate algorithm. The fluid solver uses a cell-centered finite volume solver with a second order reconstruction and a second order time-accurate method also. Both domains and solvers use their own mesh, which has required to use high order accurate methods to transfer the variables from one mesh to the other one at the fluid-structure interfaces.

A very important concept for multi-physics unsteady problems is the strong coupling. Such a coupling requires that the solutions for all the physics must be synchronized at every time step. For a monolithic approach, strong coupling can be achieved with an implicit solver that advances the full system of equations in time. But for a staggered approach, using high order implicit schemes is not sufficient because, as the fluid and the structure domains are advanced in time successively, there will always be lags between both solutions.

Achieving strong coupling by advancing respectively the fluid and the structure solutions once per time step (Loosely-Coupled Staggered Approach) is thus impossible. Note that for a steady problem solved with a pseudo-transient approach, strong coupling is automatically obtained at convergence. Focus is then done here only on unsteady problems.

Strong coupling can however be achieved if several fluid and structure computations are performed at every time step, until synchronization is obtained between the solutions (Strongly-Coupled Staggered Approach). This allows to achieve strong coupling even if explicit time-marching methods are used to integrate the equations for each domain. The disadvantage of such a method is that, as several computations are done at each time step, the computational cost is much larger. However, strong coupling allows to ensure second order time accuracy, increases the stability of the coupled algorithm, and is the only way (except if monolithic approach is considered) to ensure energy conservation at the fluid-structure interfaces. It is then highly recommended for problems with large deformation where both domains influence each other, especially is the chosen time step is quite large.

The full paper will present in more details the notion of strong coupling, as well as the numerical algorithms that have been developed inside the Flow-SCHyp project. Several examples will also be presented to validate the interest of strong coupling for the resolution of fluid-structure-interaction problems, used in combination with a staggered approach, especially as far as the improvements of the accuracy and the stability are concerned.

2 09:30 ESA Launcher Flight Dynamics Simulator used for System and Subsystem Level Analyses

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Virtual simulation is currently a key activity that supports the specification, design, verification and operations of space systems. System modelling and simulation supports in fact a number of use cases across the spacecraft development life-cycle, including activities such as system design validation, software verification & validation, spacecraft unit and sub-system test activities, etc. As the reliance on virtual modelling, simulation and justification has substantially grown in recent years, a more coordinated and consistent approach to the development of such simulation tools across project phases can bring substantial benefit in reducing the overall space programme schedule, risk and cost.
Taking advantage of TEC-MS strong expertise in dynamics (multibody software) and, in particular, in launch vehicle flight dynamics, a generic flight simulator has been built, mainly in the frame of VEGA project support, since 2001 to simulate a wide variety of launch vehicle dynamics and control at "system level". The backbone of the Flight Dynamics Simulator is DCAP (Dynamic and Control Analysis Package), a multibody software, developed by ESA together with industry, with more than 30 years heritage in Space applications. This software is a suite of fast, effective computer programs that provides the user with capability to model, simulate and analyze the dynamics and control performances of coupled rigid and flexible structural systems subjected to possibly time varying structural characteristics and space environment loads. It uses the formulation for the dynamics of multi-rigid/flexible-body systems based on Order(n). This avoids the explicit computation of a system mass matrix and its inversion, and it results in a minimum-dimension formulation exhibiting close to Order(n) behaviour, n being the number of system degrees of freedom. A dedicated symbolic manipulation pre-processor is further used in the

coding optimization. With the implementation of dedicated interfaces to other specialised software (such as NASTRAN, CATIA, Matlab/Simulink,...), it is possible to reproduce, with a quite good level of details, most of the key subsystems (such as trajectory, structures, configuration, mechanisms, aerodynamics, propulsion, GNC, propulsion,...) of the launcher in a single simulation.
Taking advantage of Multibody approach, this simulator has been easily retuned in order to be used in some CDF studies on new launch vehicle feasibility concepts. Furthermore, with some slightly modifications the simulator has been adjusted to tackle specific events such as multi-payload separation dynamics (Swarm & Galileo), thrust vector control subsystem studies (GSTP3, GSTP4 & VEGA), lift-off analysis (VEGA), general loads (VEGA). In this paper, an overview of the flight dynamics simulator capabilities is presented by illustrating the VEGA example.

3 10:00 Integrated Trajectory and Energy Management Simulator for Electric Propulsion Spacecraft

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We present a new spacecraft simulator intended to allow a realistic assessment of the behaviour of the main spacecraft subsystems in missions with electric propulsion. Built around a dedicated low thrust trajectory propagator, the simulator takes into account at each time step the exchanges of energy among the different subsystems and the instantaneous power production as a function of orbital position and spacecraft attitude. By such direct simulation approach, the mission designer is able to catch the full interplay of spacecraft dynamics, onboard energy flows and propulsive thrusting.

Energy management is a key issue in spacecraft equipped with electric propulsion systems. Such high specific impulse systems are normally operated for long durations, ranging from a few hours to several months, to impart a small but persistent acceleration to a space vehicle. Substantial delta-V may be produced in this way, resulting in large modifications to the spacecraft trajectory, using a lower propellant mass than for chemical thrusters. However, for the whole duration of thruster operation the propulsion system must be supplied with electrical power, either from the solar arrays (or other onboard generators) or from batteries. At typical power-to-thrust ratios ranging from 15 to 50 W/mN, the drain on the onboard energy reserve can be quite severe and the instantaneous power demand will have to be carefully weighed against that of the other onboard systems and, of course, of the payload. Therefore, contrary to the traditional case of impulsive chemical thrust (firing at high thrust for short duration, with negligible onboard power drain), the use of electric propulsion has a profound impact on the day-to-day management of the onboard resources.

Spacecraft dynamics under continuous electrical thrust and energy management are closely coupled: in many cases, orbital and attitude dynamics dictate the conditions for exposure to sunlight of the solar arrays (eclipse periods, angle of view, etc.) and power and energy availability govern the possibility to switch on the electric thruster, which in turn affects the dynamics, etc. In power-limited or energy-limited spacecraft, "a priori" determination of the availability of enough energy to operate the thruster (or any other power hungry subsystem) at a given moment during a mission is not trivial. Therefore, mission design with electric propulsion is normally carried out by adopting a conservative approach towards the use of onboard power; typical choices are, for example, to oversize the power system so to allow simultaneous operation of the thruster and the payload at any time; or, conversely, to restrict thruster operation to periods of payload inactivity, and vice-versa.

The simulator (SATSLab - Spacecraft Attitude, Trajectory and Subsystems Laboratory) has been developed during the last few years as a suite of software modules built around the D-Orbit core. D-Orbit is Alta's proprietary high-accuracy low thrust orbital propagator, featuring full perturbations, the possibility to simulate interplanetary trajectories, and data export for visualization in Celestia. The SATSLab modules include attitude dynamics and control, solar array and battery simulation, thruster and payload simulation. The user can describe the spacecraft geometry as a combination of pre-defined solids or import a geometry file from a commercial 3D modeler, so that shape-dependent attitude and orbital perturbations, such as those due to solar radiation pressure or to atmospheric drag, can be computed to high accuracy. SATSLab can implement a variety of in-plane and out-of-plane thrusting strategies through an user-friendly GUI or by external text-files and can be extended to any custom-tailored propulsion strategy to accommodate for specific mission needs and spacecraft resources.

The simulator is best suited for the design of missions with electric propulsion. Direct simulation enables realistic profiling of mission operations with limited onboard resources, allowing for better utilization of the spacecraft and enhanced overall performance.

This paper presents the structure of the software package and an overview of its capabilities. Some examples are given of spacecraft missions where the direct simulation approach reveals some otherwise unpredictable effects. Limitations of the simulator are addressed, as well as validation of the code by comparison with flight data from past missions.