Appendix P

**FiPS**
Thermal Fluid-Structure Interaction

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Abstract

From 2012 to today the DLR has been supporting the enhancement of FiPS® (Final Phase Simulator), an in-house developed software tool for coupled simulations, in the frame of the launcher maturation projects PREPARE (completed) and PROCEED (ongoing). This is the presentation of the achievements of the work package "FiPS®" of these two projects.

Before the PREPARE project began in 2012, a first implementation of FiPS® was used to simulate the mutual influence of upper stage movement and propellant sloshing only. In the course of further development, the feature of a thermal coupling between FLOW-3D (CFD tool) and ESATAN-TMS (thermal tool) was implemented into FiPS®. This enables the simulation of both dynamic and thermal fluid-structure interactions at the same time.

The thermal coupling is realized by a "one-to-one" approach between FLOW-3D and ESATAN-TMS. FLOW-3D uses the finite volumes method: A volume containing the geometry of interest is subdivided into smaller 3D cells. FLOW-3D's role within the thermal coupling is to calculate propellant motion and temperature distribution in the propellant's liquid and gaseous phase. ESATAN-TMS on the contrary uses the finite differences method: An object is broken down to subcomponents represented by nodes. The task of ESATAN-TMS is to compute heat conduction within the tank wall in this context. By means of a "one-to-one" approach, data exchange is realized between one FLOW-3D tank wall cell and one ESATAN-TMS transition node. This way, quantities of state, like temperature and heat flux, are transferred between the two tools at run-time. Visualization of simulation results is realized in form of diagrams and 3D animations.

Adding the feature of the thermal coupling was a logical consequence when considering cryogenic liquids as propellants. For the first time, temperature development in propellants and surrounding tank wall structures can be resolved with high precision, as the considered system reacts at simulation run-time to the motion of the propellant. Precision is only limited to the accuracy of the implemented software tools. As a consequence of temperature changes, evaporation rates and thus pressure development can be derived. This aids the improved design of structures, propulsion systems, insulations, attitude control systems, mission profiles and other design disciplines.
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WHAT IS FIPS®?

• FiPS® = Final Phase Simulator
  • Final phase of upper stage flight before (last) payload release

• Purpose: Realistic consideration of the system “upper stage”, or any other conceivable vehicle, during its flight with respect to vehicle motion and liquid propellant response (and vice versa)

• Open and closed loop control of vehicle motion is possible
  • FiPS® serves as a developing environment for space flight controllers

• Coupled analysis:
  • Dynamic interaction between vehicle dry mass (rigid body) and liquid propellant sloshing
  • Thermal interaction between vehicle structure (tank walls) and propellant (liquid and gas)
02
FUNCTIONAL BACKGROUND
03 THERMAL COUPLING
MODELLING APPROACH

FLOW-3D (CFD)

- Finite volume method

ESATAN-TMS (THERMAL)

- Finite differences method

one cell = one transition node

MODELLING IMPLEMENTATION

- Problem: ESATAN upper stage tank modelling not as fine as FLOW-3D meshing

- Solution: Several transition nodes assigned to adjacent ESATAN shells/solids

- Heat fluxes from FLOW-3D are summed up before rendering to ESATAN-TMS by means of the transition nodes

- All transition nodes assigned to a single ESATAN shell/solid receive the shell/solid’s temperature

- Exchange of data at runtime (time step size regulated by FLOW-3D)
VISUALIZATION BASICS

• General:
  • VRML and Java used for visualization
  • Vehicle motion information retrieved from MATLAB/Simulink
  • Liquid propellant location (distribution and motion) provided by FLOW-3D

• Dynamic mode only:
  • Each liquid propellant is assigned a color (monochromatic)
  • Focus is laid on vehicle and liquid propellant dynamical behavior due to mission flight profile only
VISUALIZATION ENHANCED

- Dynamic and thermal mode combined:
  - Tank view:
    - Tank wall temperatures shown in swung-open view per tank
    - Liquid propellant is shown as a greyed-out half-transparent mass
  - Vehicle view:
    - One propellant is assigned a color according to its temperature distribution at a time. Meanwhile, the other propellant is greyed-out
    - It can be switched between the propellants, depending on which one is desired to be shown and to be colored due to its temperature distribution

05
SUMMARY & OUTLOOK
SUMMARY

- **FiPS®** is a tool to simulate coupled processes of a vehicle’s system
  - Basis of FiPS® is the coupling of rigid body dynamics with liquid propellant motion
- **Thermal coupling added to FiPS®**
  - Exchange of thermal data between FLOW-3D and ESATAN-TMS at runtime during a simulation
  - FLOW-3D gives heat fluxes to ESATAN-TMS; ESATAN-TMS gives tank wall temperatures to FLOW-3D
  - Pressure development inside of the tanks can be used as an input for thruster models (propulsion)
- **Visualization**
  - Liquid propellant and tank wall temperature can be displayed in different view modes

OUTLOOK

- **Concurrent developments**
  - Implementation of a full vehicle ESATAN-TMS thermal model: Enables simulation of entire vehicles thermal household taking into account both conductive and radiative calculations (the latter depending on orbit propagation)
  - A FiPS® remote version: network communication between customer and FiPS®; customer can test & apply (analysis) own control algorithms without revelation of own know-how; customer can conduct sensitive applications with access restrictions
- **Applications**
  - So far: Ariane 5 (ESC-A, ESC-B, ME), ATV, MPCV (Orion), LNG (liquid natural gas) tank ships, satellites
  - Currently: A6, Eurofighter, NGSAR
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THANK YOU FOR YOUR ATTENTION!
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