ATPE Simulator: Simulation Tool for Onboard GNC Development and Validation

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Overall Simulator Concept

- **Trajectory analysis**
  - Mission design (3-DOF)
  - Simulator A

- **Flight Mechanics (FM)**
  - 6-DOF
  - Simulator B

- **GNC Design**
  - 6-DOF
  - Simulator C

- **GNC Detailed Design**
  - 6-DOF
  - Simulator D

- **GNC Flight S/W**
  - Real-Time
  - Simulator E

Measures to enhance Efficiency

Definition of a **Unified Simulator Family**
- Reuse of components as single-source models
- Integrated design approach
- Use COTS SW for GNC development & SW engineering process

- Reduce costs
- Reduce turn around cycle after problem identification
- Simplify IF to external partners
ATPE Simulator Approach

1. Design and preliminary evaluation of GNC onboard software within engineering environment (minimize extra effort for SW development as much as possible)

2. Rapid software migration to real time environment via autocoding

3. GNC on-board software validation in real time

- Tools:
  - Development simulator
  - Autocoding tools
  - Real time simulator
ATPE Simulator Introduction

- Developed within ATPE (Aeroassist Technologies for Planetary Exploration) project, under contract to ESA
  - Technology development study, targeting the design, development and test of GNC for aeroassist technologies for planetary exploration

- Extended to other mission phases after ATPE project, e.g.:
  - Pre and post aerocapture phases (ATPE CCN)
  - Mars Ascent in the frame of the Planetary Ascent Vehicle Contract (models implemented by SciSys (UK))
  - RLV end-to-end simulation (internal studies and ASTRA)
  - Small capsule entry (PARES)
Simulator User Requirements

- The simulator shall be modular, easy-to-use, and expandable
- The simulator shall support the design and evaluation of GNC algorithms
- The simulator shall include
  - 3 and 6 DOF dynamics, environment models, vehicle models including aerodynamics and propulsion, sensor models, and actuators models
- Simulator architecture and coding standards shall support the migration to real-time environment
- The following functionalities shall be included
  - Monte-Carlo
  - Graphical User Interface (GUI)
  - Interface to ESA’s trajectory optimization tool ASTOS
  - Interface to visualization tool STK

- Simulator was implemented in Matlab/Simulink
## Mission Phases Simulated during ATPE

<table>
<thead>
<tr>
<th>Mission Type</th>
<th>Aero Capture (AC)</th>
<th>Aero Braking (AB)</th>
<th>Aero Gravity Assist (AGA)</th>
<th>Entry</th>
<th>Parafoil</th>
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<tr>
<td>MM (Manned Mars)</td>
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<td>EDM (Earth Demo Mission)</td>
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Mission Phases Simulated up to now (extension to ATPE project)

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<th>Ascent</th>
<th>AC</th>
<th>Pre AC</th>
<th>Post AC</th>
<th>AB</th>
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<th>Entry</th>
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</table>
Simulator Structure

1. User Interface:
   - Interface

2. Mission Definition:
   - Mission A
   - Mission B
   - Mission C

   Mission Phases:
   - Phase 1
   - Phase 2
   - Phase 3
   - Phase 4
   - Phase 5

   Kernel Models:
   - Initial Workspace
   - Simulink Kernel Model for Phase 3
   - Simulation Results

3. Model Library:
   - 6 DoF Dyn
   - Navigation
   - Aerodyn
   - Guidance
   - Environment
   - Control
   - Simulator
   - Onboard S/W
Simulator Structure (cont)

Simulink Kernel Model

<table>
<thead>
<tr>
<th>User Interface</th>
<th>Graphical User Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mission Definition</td>
<td>Mission A</td>
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<tr>
<td>Mission Phases</td>
<td>Phase 1</td>
</tr>
<tr>
<td>Kernel Models</td>
<td>Initial Workspace</td>
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<tr>
<td>Model Library</td>
<td>6 DoF Dyn</td>
</tr>
<tr>
<td></td>
<td>Simulator Onboard S/W</td>
</tr>
</tbody>
</table>

Simulink Kernel Model for Phase 3:

ATPE Simulator
Mars Sample Return Mission
Entry of Earth

Simulink Flowchart:
- Sensors
- Navigator
- Control
- Environment
- 6-DoF Dynamic
- Forces & Torques
Simulator Structure (cont)

Graphical User Interface

Mission A
Mission B
Mission C

Mission Phases:
Phase 1
Phase 2
Phase 3
Phase 4
Phase 5

Kernel Models:
Initial Workspace
Simulink Kernel Model for Phase 3
Simulation Results

Model Library:
6 DoF Dyn
Navigation
Section
Guidance
Environment
Control
Simulator
Onboard S/W

Simulink Function Module

INPUT
PARAMETER
OUTPUT

Simulink Function Module

Simulink Function Module

Controlled by Function ICD
- Input
- Output
- Parameter

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2-5 October 2006
### Libraries

- **Onboard Library**
  - Guidance, Navigation & Control for: aerocapture, aerobraking, aerogravity assist, entry, Mars ascent, TAEM, and parafoil

- **Model Library**
  - Actuator models: Attitude control thrusters, trajectory control thrusters, aerodynamic surfaces, winch models
  - Aerodynamic models: Inflatable spacecraft, Apollo-like spacecraft, waverider, Mars Launcher, Hopper, PARES
  - Dynamic models: 6-dof, 3-dof, 4-dof (Parafoil)
  - Propulsion models: Hopper, Mars Launcher
  - Environment models: Earth, Mars, Sun, Venus, Jupiter
  - Sensor models: INS, radar altimeter, GPS, Star-tracker, DSN
  - Transformations: Approx. 50 frame transformations
Other Functionalities

- Graphical User Interface
  - run, modify, and analyze results of all mission phases.

- Monte Carlo capability
  - Main uncertainties considered:
    - mass, CoG location, aerodynamic coefficients, propulsion characteristics, RCS and TCM thrust, sensor characteristics, atmospheric and environment characteristics, initial conditions

- STK and ASTOS interfaces
  - ATPE simulator receives input data from ASTOS, and automatically updates the required initialization files.
  - STK interface is included for detailed visualization
Migration to Realtime Environment

Migration to a representative real-time environment in a two board implementation

Single board PPC VME based rack

Motorola MVME 5100 with 450 MHz Power PC CPU

Tornado host Environment (Win2000)

Ethernet Local network
RT Migration Process
Two Chassis Implementation

Software transfer from Simulink to RT ANSI-C tasks directly from s-function interface or via autocoding

Software transfer from Simulink to WS via autocoding

Network connection by means of a socket interface provided by EADS ST Libraries
Unified Simulator Concept → So Far Achieved

- Simulator Family Approach initiated, First Applications
  - X-38, Phoenix, ATPE

- Usage of Commercial GNC Development Tools
  - Matlab/Simulink

- Reuse of components
  - Based on Simulink library
  - Autocoding of Simulink modules via Matlab‘s Realtime Workshop

- Usage of Commercial S/W Engineering Tools
  - Only in part: S/W configuration management with Perforce
  - Planned next step: Coupling of S/W engineering methods and tools with GNC development process, e.g. application of UML and tools like Artisan or Rational Rose
ATPE Simulator Extensions for Mars Mission Analysis (1)

- ATPE simulator upgrade Apr-Jul 2005
  - Decelerator system model
    - Multiple stage round parachutes (user defined)
    - Modeling of filling process
    - 6-DoF dynamics of descent configuration with variable mass
  - Fixed thrust retro-rocket system
    - Interfacing with existing ATPE Mars entry scenarios
  - Monte Carlo simulation capability
    - Density and 3D wind model
    - Decelerator system parameters
    - Entry phase dispersion
ATPE Simulator Extensions for Mars Mission Analysis (2)

- ATPE simulator upgrade Aug-Dec 2005
  - Powered landing (Viking type)
    - Spin off from lunar landing initiative
    - 6 DoF rigid body dynamics with variable mass
    - Pulse modulated thruster management function
    - Slew angle controlled horizontal displacement
    - Navigation represented by parametric transfer functions
  - Interfacing with existing ATPE Mars entry scenarios
  - Monte Carlo simulation capability
    - Density and 3D wind model
    - Decelerator system parameters
    - RCS performance parameters
ATPE Simulator Extensions for Mars Mission Analysis (3)

- ATPE simulator upgrade Jan-Apr 2006
  - Retro Rocket Firing Control Algorithm
    - Fixed thrust retro-rocket system
      (single or dual stage)
    - Fixed thrust lateral rocket system ("TIRS")
    - Closed loop firing logic implementation for mitigation of descent speed, wind, density, thrust variation
  - Interfacing with existing ATPE Mars entry scenarios
  - Monte Carlo simulation capability
    - Density and 3D wind model
    - Decelerator system parameters
    - RCS performance parameters
ATPE Simulator Extensions for Mars Mission Analysis (4)

- ATPE simulator upgrade May-Jul 2006
  - Multi-Body parachute descent dynamics model
    - Using Matlab SimMechanis toolbox
    - Equivalent rigid body models of parachute canopy, backshell, lander
    - Parachute apparent mass effects
    - Elastic bridles and lines with damping
    - Suspension tripods as nonlinear joints
    - Retro rocket and TIRS rocket systems
  - Standalone tool using ATPE coding standards & libraries
  - Used for analysis of retro rocket phase dynamics and firing logic performance analyses
  - Fast engineering tool version for MC analysis, needs parameters from high fidelity FE models to be accurate
Summary

• Aeroassist Maneuver Simulation Tool:
  – Modular, expandable and flexible
  – Covering all envisaged mission phases
  – Includes GUI, Monte-Carlo capability, and ASTOS & STK interfaces
  – Design supports the transfer to a representative real-time environment

• First applications:
  – X-38, Phoenix, ATPE
  – Extension for Mission analysis for Mars descent scenarios (e.g. Exomars)

• Next steps:
  – Extension for: RLV’s (Hopper end-to-end simulation tool) and Small entry capsules (PARES)