Formation Flying and Rendezvous and Docking Simulator for Exploration Missions (FAMOS-V2)

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Introduction to FAMOS-V2
  • FAMOS-V2 Description
  • General architecture
  • FAMOS-V2 Propagator

Launcher ascent

Rendezvous and Docking
  • Change of plane
  • Rendezvous and Docking manoeuvres

Validation Scenarios Overview

FAMOS-V2 Demonstration
INTRODUCTION TO FAMOS-V2
What’s FAMOS-V2?

- SW tool designed and developed by GMV S.A., Spain, under GSTP contract with ESA/ESTEC.

What FAMOS-V2 is meant for?

- Simulate Rendezvous and Docking sequences on Circular and Elliptical orbits for exploration mission-scenarios such us: Venus, Earth, Moon, Mars, Deimos, Triton and Europa.
- Cover launching phase of the second spacecraft involved in the RvD once it has left from Earth, Moon and Mars surfaces.

How FAMOS-V2 has been developed?

- Two phases:
  - Simplified Version
  - Full Version
FAMOS-V2 Simplified Version (1/2):

- Open loop: no sensors or actuators
- Corrective manoeuvres
- Three degrees of freedom
- Environment: drag, solar radiation, third body, non-sphericity
- Launch ascent optimisation
FAMOS-V2 Simplified Version (2/2):

- Available Orbital Manoeuvres for Rendezvous:

**Circular:**
- Hopping on V-bar
- Hohmann Re-phasing
- Hohmann Transfer
- Two Points Transfer
- Continuous Tangential Transfer
- Continuous Hopping on V-bar
- Applied Delta-V
- Station Keeping
- Forced Motion

**Elliptical:**
- Hopping on V-bar
- Re-phasing in Time
- Height Transfer
- Two Points Transfer
- Applied Delta-V
- Station Keeping
- Forced Motion
FAMOS-V2 Full Version: Simplified Version plus:

- Close loop: feedback of sensors and actuators
- Six degrees of freedom (translation + attitude)
- Communications module
- Guidance, Navigation and Control (GNC)
Introduction to FAMOS-V2 Execution

- Definition of inputs
- Execution of simulation
- Visualization of results
The architecture of FAMOS-V2 has been designed to achieve these three tasks.
FAMOS-V2 Propagator

- Full Cowell numerical propagator, Domand-Prince (ode5)
  - Propagation around the following central bodies:
    - Venus, Earth, Mars, Moon, Deimos, Europa and Triton

- Four types of perturbation can be considered:
  - Aerodynamic drag perturbation
  - Solar radiation pressure perturbation
  - Non-sphericity perturbation
  - Third body perturbation

- Simplified propagator for launcher ascent:
  - J2 and Aerodynamic drag perturbations
The Launch ascent phases:

- **First Phase**: 1st stage ignition. Launch with a small acceleration to allow passing through the dense atmospheric layers with a low dynamic pressure.
- **Second Phase**: Coast arc. At this time the rocket will not have any thrust.
- **Third Phase**: 2nd Stage. Bi-linear tangent law.

<table>
<thead>
<tr>
<th>Drag coefficient</th>
<th>1st Stage</th>
<th>Coast Arc</th>
<th>2nd Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
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<tr>
<td>Reference diameter</td>
<td>0.563</td>
<td>0.563</td>
<td>0.315</td>
</tr>
<tr>
<td>Nominal burn time</td>
<td>197.566s</td>
<td>--</td>
<td>672.1973s</td>
</tr>
<tr>
<td>Propellant mass</td>
<td>360 kg</td>
<td>--</td>
<td>116 kg</td>
</tr>
<tr>
<td>Gross mass</td>
<td>456.6 kg</td>
<td>--</td>
<td>213.8 kg</td>
</tr>
<tr>
<td>Isp</td>
<td>306 s</td>
<td>--</td>
<td>326 s</td>
</tr>
</tbody>
</table>

- Maximum aerothermal flux: 5 W/cm²
- Nose curvature radius: 0.2 m
- Aerothermal flux coefficient: 18.8, 0.5, 3
Matlab "fmincon" optimiser is used, which can impose equality and inequality constraints. The optimiser tries to maximize the payload mass to be delivered into orbit.

Aerothermal flux simulated.
## Optimisation options

<table>
<thead>
<tr>
<th>Optimization</th>
<th>Equality constraints</th>
<th>Inequality constraints</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>• Final PAV semi-major axis&lt;br&gt;• Final PAV eccentricity&lt;br&gt;• Final PAV inclination&lt;br&gt;• Final PAV argument of perigee</td>
<td>• Optimum trajectory above planet surface&lt;br&gt;• Max. Aerothermal flux less than max. Aerothermal limit</td>
<td>• Optimum PAV payload mass&lt;br&gt;• Optimum PAV RAAN&lt;br&gt;• Optimum PAV Argument of Latitude</td>
</tr>
<tr>
<td>RAAN</td>
<td>• Final PAV semi-major axis&lt;br&gt;• Final PAV eccentricity&lt;br&gt;• Final PAV inclination&lt;br&gt;• Final PAV RAAN&lt;br&gt;• Final PAV argument of perigee</td>
<td>• Optimum trajectory above planet surface&lt;br&gt;• Max. Aerothermal flux less than max. Aerothermal limit</td>
<td>• Optimum PAV payload mass&lt;br&gt;• PAV Argument of Latitude</td>
</tr>
<tr>
<td>Argument of Latitude</td>
<td>• Final PAV semi-major axis&lt;br&gt;• Final PAV eccentricity&lt;br&gt;• Final PAV inclination&lt;br&gt;• Final PAV RAAN&lt;br&gt;• Final PAV argument of perigee</td>
<td>• Optimum trajectory above planet surface&lt;br&gt;• Max. Aerothermal flux less than max. Aerothermal limit&lt;br&gt;• Final PAV and Orbiter relative argument of latitude greater than a minimum&lt;br&gt;• Final PAV and Orbiter relative argument of latitude less than a maximum</td>
<td>• Optimum PAV payload mass&lt;br&gt;• PAV Argument of Latitude&lt;br&gt;• Orbiter Argument of Latitude</td>
</tr>
</tbody>
</table>
Rendezvous & Docking
Change of plane manoeuvre:

- Previous to Rendezvous and Docking manoeuvres
- Corrects *inclination* and *RAAN* for flyer satellite
- Impulsive manoeuvre: optimum points for impulses minimizing total delta-V
- Free drift until desired along track distance achieved
“Large scale” Approach Manoeuvres:
- Rough approach

Final Approach Manoeuvres (typically 5000-0 m):
- Precise and slow approach
- Position keeping

Collision Avoidance Manoeuvre

Corrective Manoeuvres
Circular Orbeuves for Rendezvous:
- Impulsive Hopping on V-bar
- Impulsive Hohmann Re-phasing
- Impulsive Hohmann Transfer
- Impulsive Two Points Transfer
- Continuous Tangential Transfer
- Continuous Hopping on V-bar
- Applied Delta-V
- Station Keeping
- Forced Motion
The aim of the elliptical approach manoeuvre is to bring, in a high elliptical orbit, the chaser to a delayed position w.r.t the target.

Parameters provided by the user:
- Virtual manoeuvre duration or time constant (T)
- Real manoeuvre duration (T_d)
- Final position defined as:
  - Time Delay (τ) of chaser respect to target (re-phasing in time)
  - Relative position of chaser respect to target
The delayed position (only for “re-phasing in time” manoeuvre) is expressed as:

\[ \bar{X}_{\text{chaser}}(t_f) \rightarrow \bar{X}_{\text{target}}(t_f - t) \]

Where

- \( \tau \) is the delay time of chaser w.r.t the target
- \( t_f \) is the time at the end of the manoeuvre

The final position is expressed respect to target.

The Elliptical Approach algorithm is based in the Transition Matrix:

\[ \delta \bar{x}_f = \Phi(t_f, t_0)\delta \bar{x}_0 \]
Elliptical Orbits (3): Available Manoeuvres

Elliptical Manoeuvres for Rendezvous:

- Hopping on V-bar
- Re-phasing in Time
- Height Transfer
- Two Points Transfer
- Applied Delta-V
- Station Keeping
- Forced Motion

“Large scale” approach

Final approach
FAMOS-V2 Full version introduces the following capabilities *(available from October 2004)*:

- Rendezvous Attitude Dynamics
- Rendezvous Sensors
- Rendezvous Actuators
- Rendezvous Navigation (Absolute and Relative)
- Communication Module
- Additional Visualization capabilities.
- RF
- CAMERA
- Lidar
- IMU:
  - Gyroscope
  - Accelerometer
- STR
- SAS (Developed by GMV)
Additional Visualization capabilities: Attitude Guidance

- Fix Relative
- Target Pointing
- Sun Pointing
- Absolute Pointing
Validation Scenarios

- **Circular:**
  - Mars Sample Return (Launch ascent from Mars)
  - Mars Sample Return (Change of Plane & Rendezvous)
  - Deimos Sample Return (RvD with Deimos)
  - Human Lunar Mission (Ascent)
  - Human Lunar Mission (Rendezvous)
  - ATV Mission (Rendezvous)

- **Elliptic**
  - Launch Ascent to Elliptical Orbit
  - ATV RvD with Corrective Manoeuvres
  - Elliptical Approach

Courtesy of NASA

Courtesy of ESA