Launch Vehicle Design and GNC Sizing with ASTOS

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Outline

- Company presentation
- ASTOS
- Vehicle design
- GNC sizing
- Safety analysis
- Summary

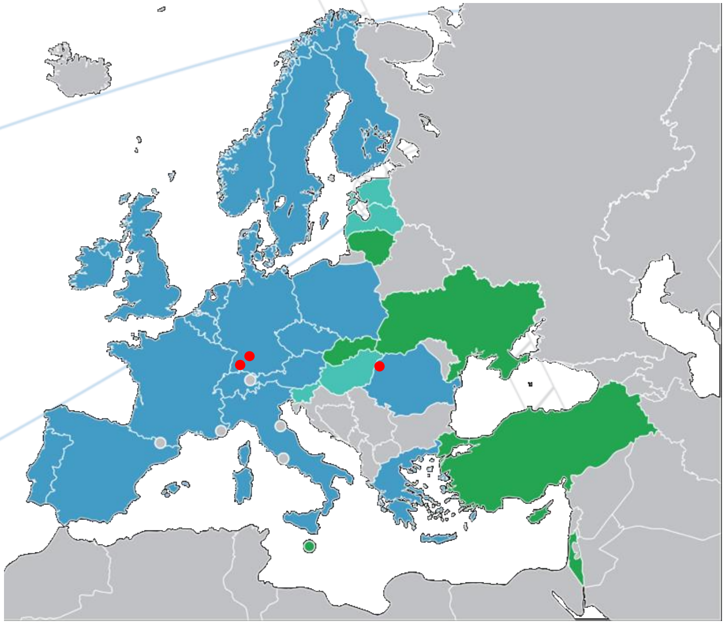
Astos Solutions

COMPANY PRESENTATION

Astos Solutions Overview

- SME with sites in Unterkirnach (DE), Stuttgart (DE), Oradea/Sibiu (RO)
- Spin-Off of the Univ. of Stuttgart, standalone company since 2006
- Roots of Astos Solutions go back to 1989

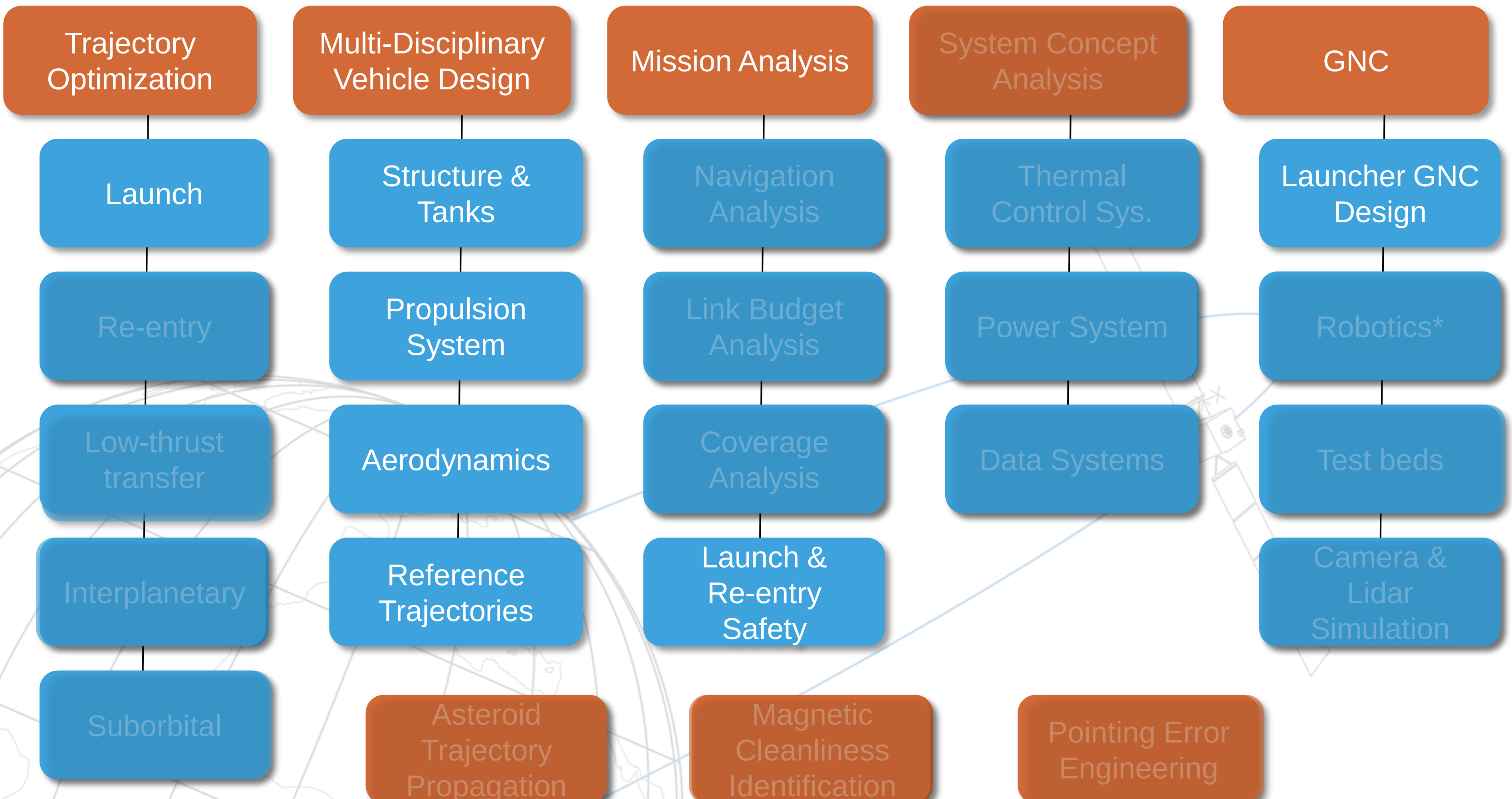
Office in Stuttgart



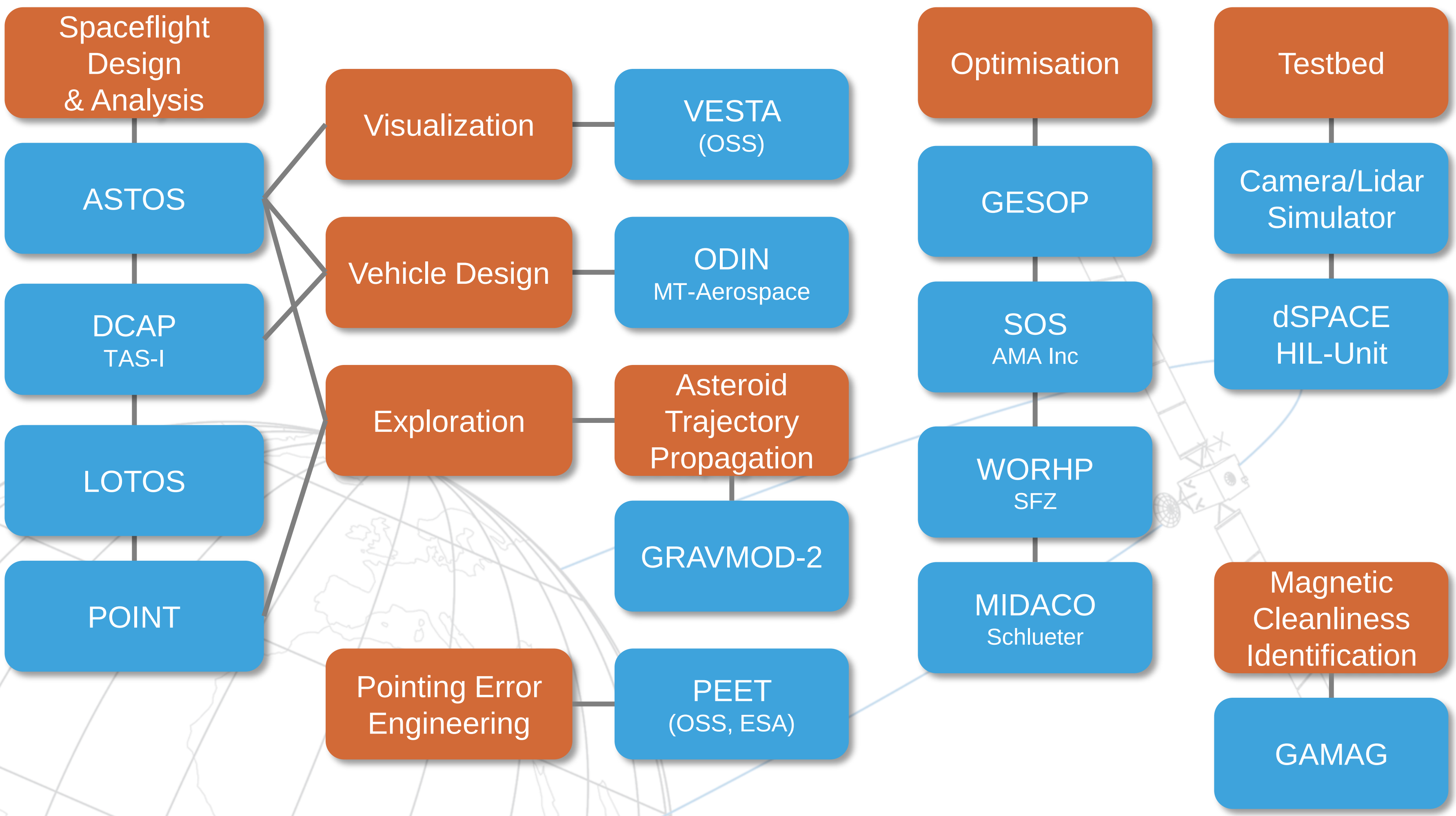
Astos Solutions’ Expertise

- **Trajectory Optimization**
  - Launch
  - Re-entry
  - Low-thrust transfer
  - Interplanetary
  - Suborbital
- **Multi-Disciplinary Vehicle Design**
  - Structure & Tanks
  - Propulsion System
  - Aerodynamics
  - Reference Trajectories
- **Mission Analysis**
  - Navigation Analysis
  - Link Budget Analysis
  - Coverage Analysis
  - Launch & Re-entry Safety
- **System Concept Analysis**
  - Thermal Control Sys.
  - Power System
  - Data Systems
- **GNC**
  - Launcher GNC Design
  - Robotics
  - Test beds
  - Camera & Lidar Simulation
- **Asteroid Trajectory Propagation**
- **Magnetic Cleanliness Identification**
- **Pointing Error Engineering**

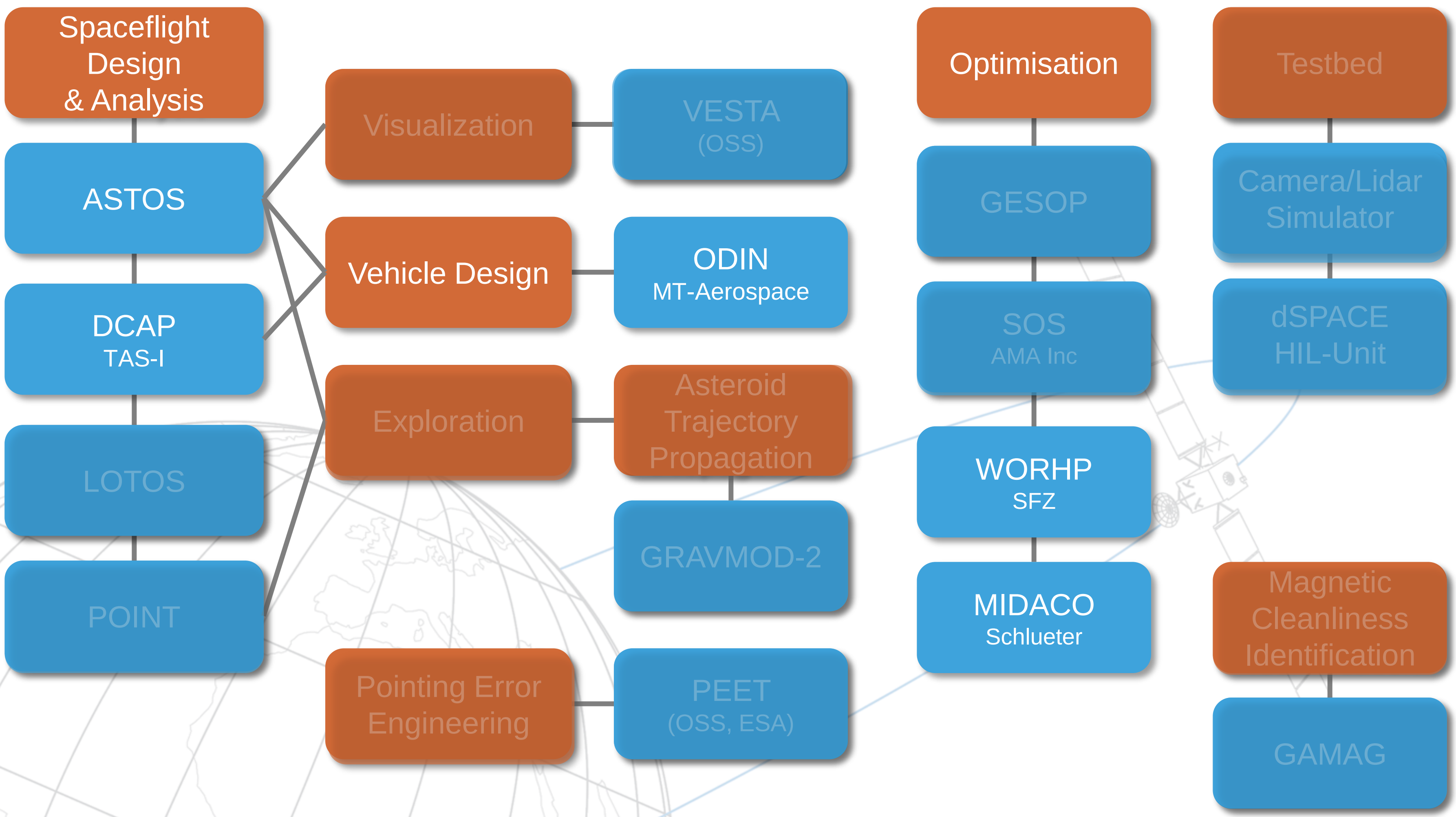
Astos Solutions' Releveant Expertise



Product Portfolio



Applicable Product Portfolio



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ASTOS

ASTOS From Past to Future

Past – Since 1989 up to ASTOS 7

- „I know ASTOS as a trajectory optimization tool“

Present – ASTOS 8.0

- Launcher Design up to Phase B
- Mission Analysis
- GNC Design & Analysis
- Functional Engineering Simulation

Near future – ASTOS 8.1

- System Concept Simulation

ASTOS Current Projects – MDO

- Creation ASTOS models of several Ariane 6 configurations with vehicle structures according to a load case analysis
- Examples of configurations computed includes:
  - RFP with separated tanks or common bulkhead
  - Airbus-Safrane concept
  - Kerosene concept
- Astos Solutions is sub-contractor and responsible for:
  - Computation of the payload for reference configurations
  - Computation of the structure masses according to the load case analysis.

- Prime: MT-Aerospace Augsburg

ASTOS Current Projects – MDO/GNC

- Design of a new small launcher for the Asian market
- Several design phases, first beginning in 2010.
- Astos Solutions is prime contractor and is responsible for:
  - Design of the vehicle structure considering load case analysis
  - Design of the GNC including flexible dynamics
  - Analysis of GNC with respect to injection accuracy
  - Safety aspects: launch range safety assessment and design of the neutralization system

- Customer: ATI Japan
- Sub-contractor: MT-Aerospace Augsburg (DE)

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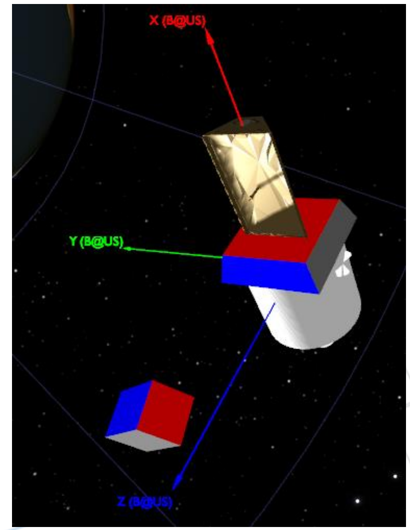
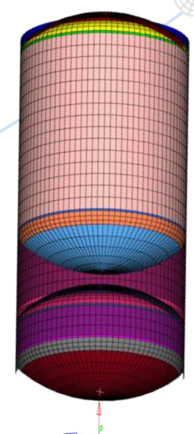
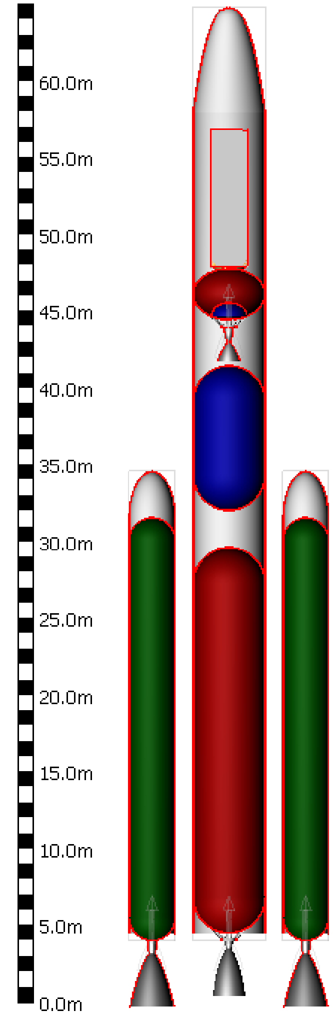
VEHICLE DESIGN

Space Transportation – Launcher Design

- Trajectory optimization
  - Reference trajectories for GNC
  - Payload performance
  - Multi-payload deployment
- Vehicle design optimization
  - Stage sizing
  - Structural optimization with load case analysis and ODIN
  - Rocket motor design with RPA and ESPSS
  - Controllability analysis
  - FE-model export using smeared wall thickness



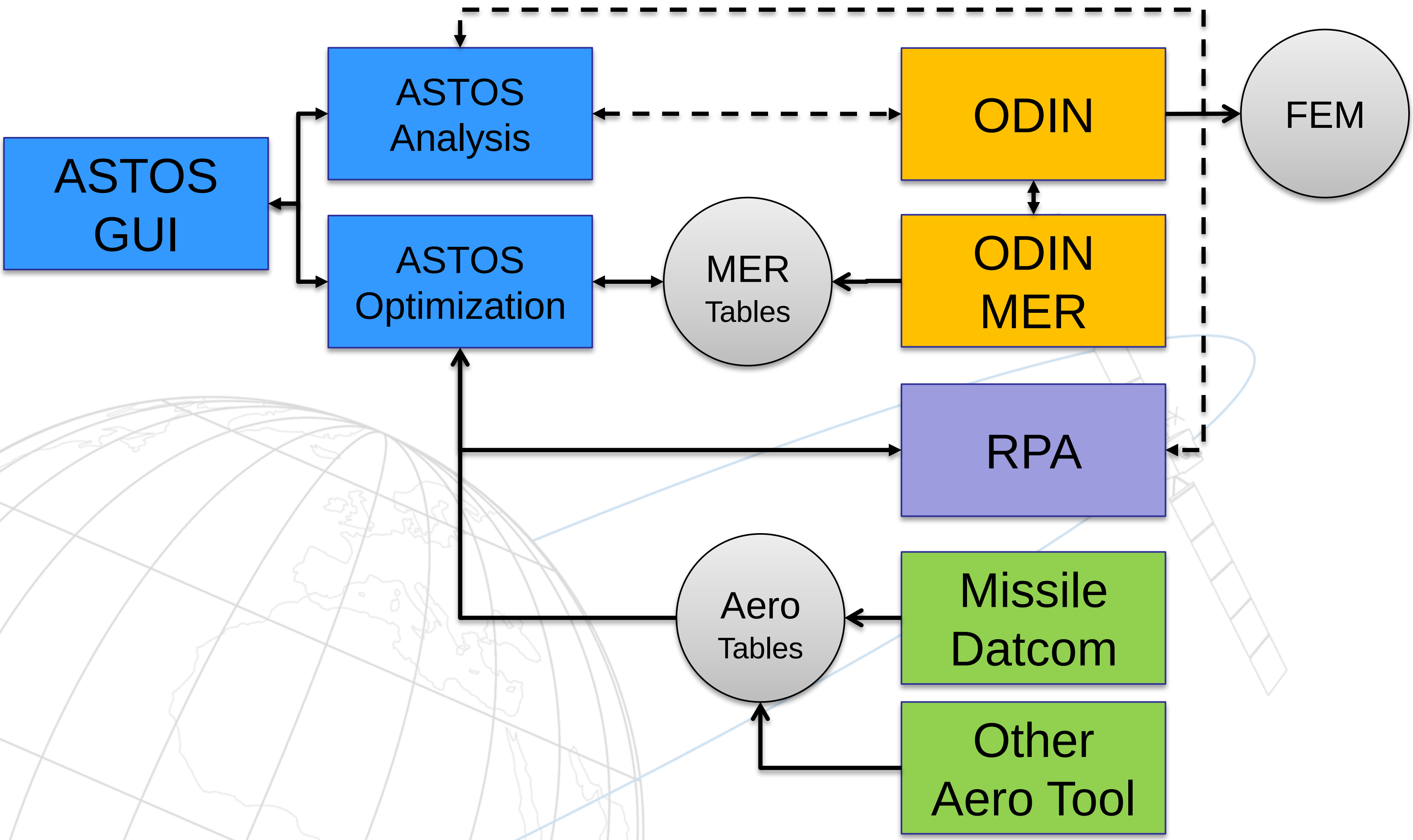




Multidisciplinary Design Optimization

- Fast aerodynamics computation
  - SOSE (surface inclination method)
  - Missile Datcom for launchers
- Propulsion system
  - Chemical equilibrium in chamber based on RPA
  - Regression of efficiency and engine mass for various engine and propellant types
  - Preliminary cycle analysis
  - Thermal analysis and cooling design
  - Flow separation in nozzle
  - Approximation of solid propellant motors
- Structures based on substructures

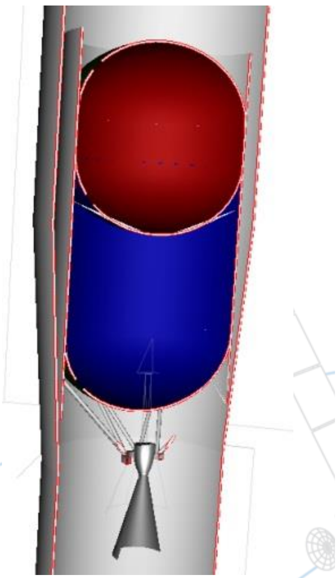
Architecture

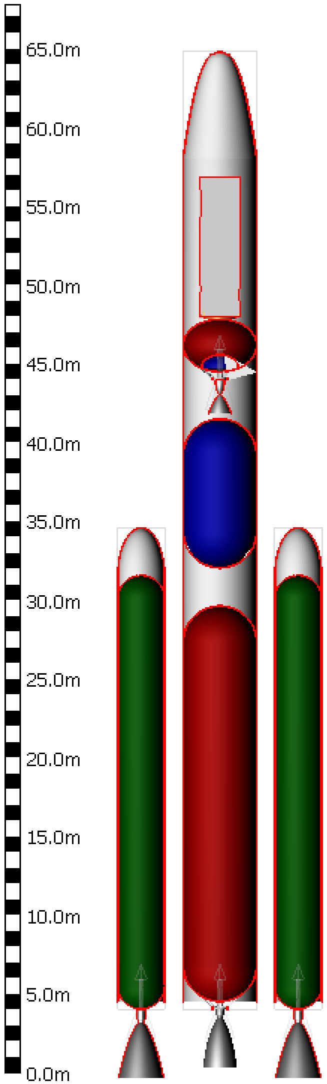


Launcher Geometry

- Supported configurations
  - Single core launcher with several stages
  - Upper stage under fairing
  - Hammerhead configuration
  - Core stage with strap-on boosters
- Various tank configurations
  - Separated tank
  - Common bulkhead
  - Enclosed tank
- Engines are attached
  at a thrust frame

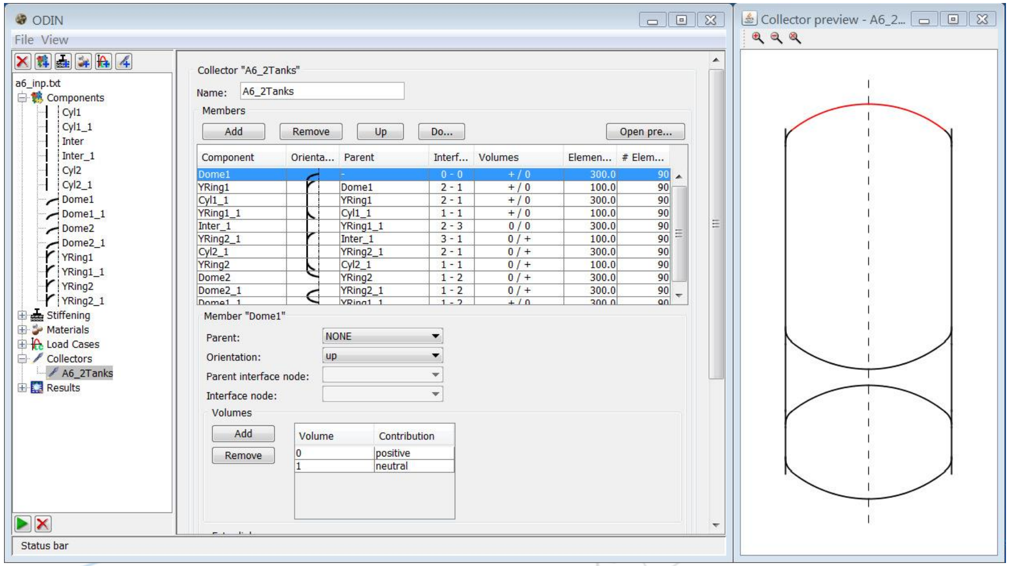
=> Computation of COM and MOI
assuming shell structures and tank filling

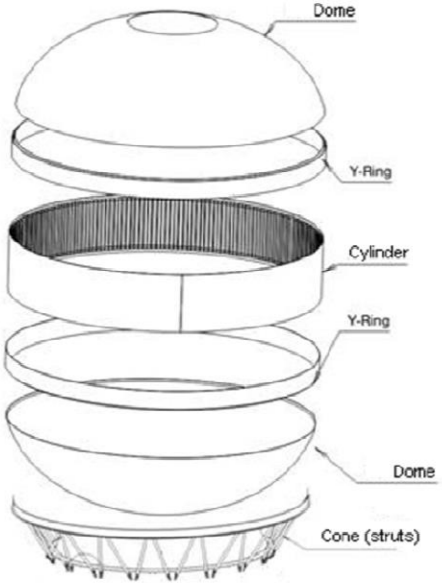




ODIN

- Modelling on substructure level
  - Cylinders, cones, domes, y-rings, struts
  - User defined isotropic material including smeared CFRP
  - Stiffening concepts: isotropic, othogrid, sandwich

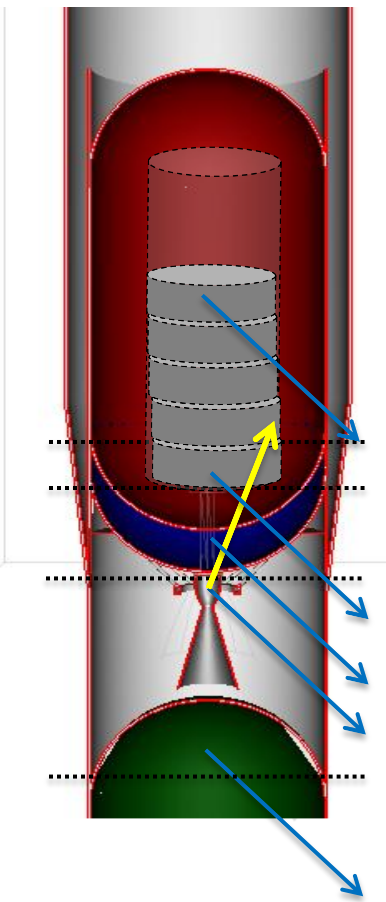




- Structural mass optimization based on ODIN
- Mass regression based on
  - Geometry
  - Material & stiffening concept
  - Dimensioning load case

Load Case Analysis

- Determination of dimensioning load case
  - shell structure formed as 1-D beam
  - Defined by stages or substructures with cutting planes
  - Flight and ground load cases (with filling phase)
- Based on
  - Variable tank pressure
  - Perturbed external forces and moments (aero & TVC with wind gust, CR>1.5)
  - Resulting distributed point mass acceleration
  - Booster attachment forces
- Used for
  - Structural mass estimation based on geometry, load case, material and stiffening concept
  - Structural optimization performed by ODIN



MDO Output

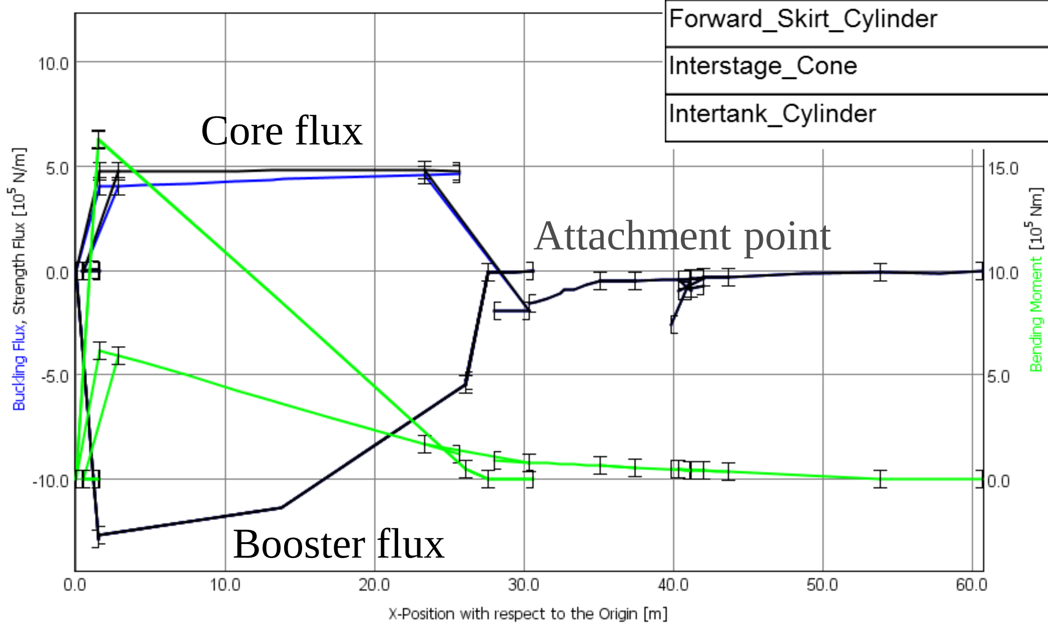
- Figures
  - Graphical representation
- Plots
  - Trajectory
  - COM and MOI evolution
  - Flux and pressure over x position for each dimensioning load case

- Tables
  - Stage dimensions and masses
  - Final Orbit
  - Key trajectory events comprising time points of maximum loads & phases and dimensioning line loads
  - Table of substructures with stiffening concept, dimensions, mass and comparison with ODIN mass

Automatic template creation and completion!

MDO Output Example

Stage 1 Components	Mass [kg]	Stiffening	Height [m]	Diameter [m]	Strength		Buck Flux
					Flux	pres	
Aft_Bulkhead_Fuel_Tank	451.2	sandwich	2.4	4.7	0	2.23	1
Aft_Bulkhead_Oxidizer_Tank	302.8	orthogrid	2.4	4.7	-195	3.37	-17
Aft_Skirt_Cylinder	74.6	isotropic	1.2	4.7	0.2	0	0
Cylindrical_Part_Fuel_Tank	**2,667.2**	**sandwich**	**20.4**	**4.7**	**333**	**2.15**	**1.4**
Cylindrical_Part_Oxidizer_Tank	469.1	orthogrid	4.8	4.7	-155	2.89	-66
Forward_Bulkhead_Fuel_Tank	450.8	sandwich	2.4	4.7	2.4	0	2.4
Forward_Bulkhead_Oxidizer_Tank	295.8	orthogrid	2.4	4.7	-29	0	-15
Forward_Skirt_Cylinder	467.4	isotropic	2.4	4.7	-118	0	-118
Interstage_Cone	876.3	isotropic	3.7	4.7	-112	0	-112
Intertank_Cylinder	634.6	orthogrid	7.1	4.7	425	0	-197



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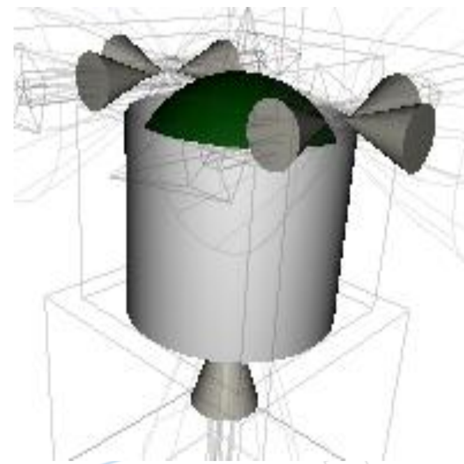
GNC SIZING

Space Transportation
Launcher GNC

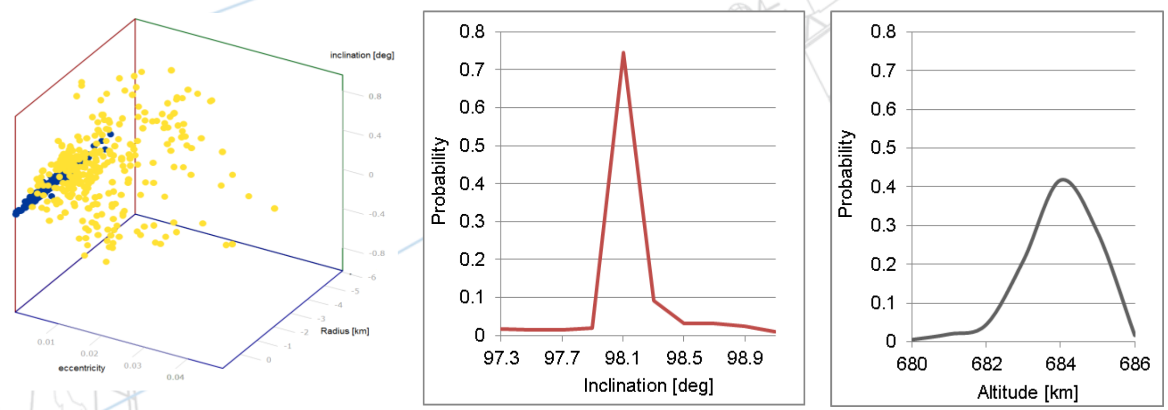
GNC Design

- LGSST project, ESA TRP
- GNC algorithms under Simulink
- DACP computes mode shapes
  - propellant sloshing included
- ASTOS linearized flexible dynamics



Output

- Actuator sizing
- Max TVC angles
- Launcher performance
  - injection accuracy
- GNC performance
- Worst case analysis



Orbit injection, probability final altitude (black) and orbit inclination (red)

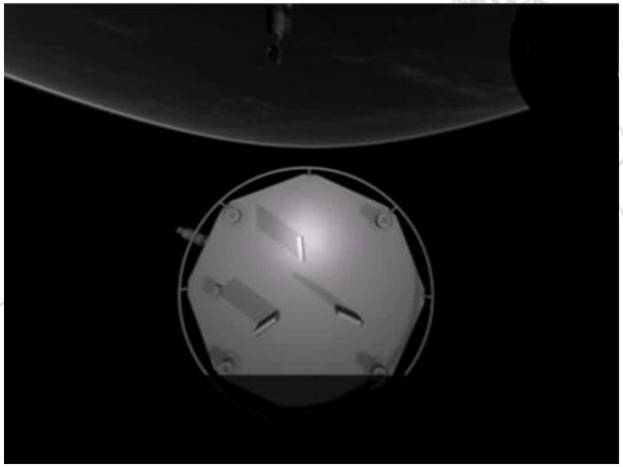
GNC Design & Analysis

Conceptual Design
- (optimal) controlled vehicle attitude
- Instantaneous pointing laws of vehicle and sensors

Preliminary/Detailed Design
- Stepwise switch to Simulink

Advanced Features
- Matlab design toolbox reading data from ASTOS
- Real time animation with VESTA with force/moment feedback

➢ Navigation extension with Camera Simulator



Multi-Body Flexible Dynamics (DCAP)

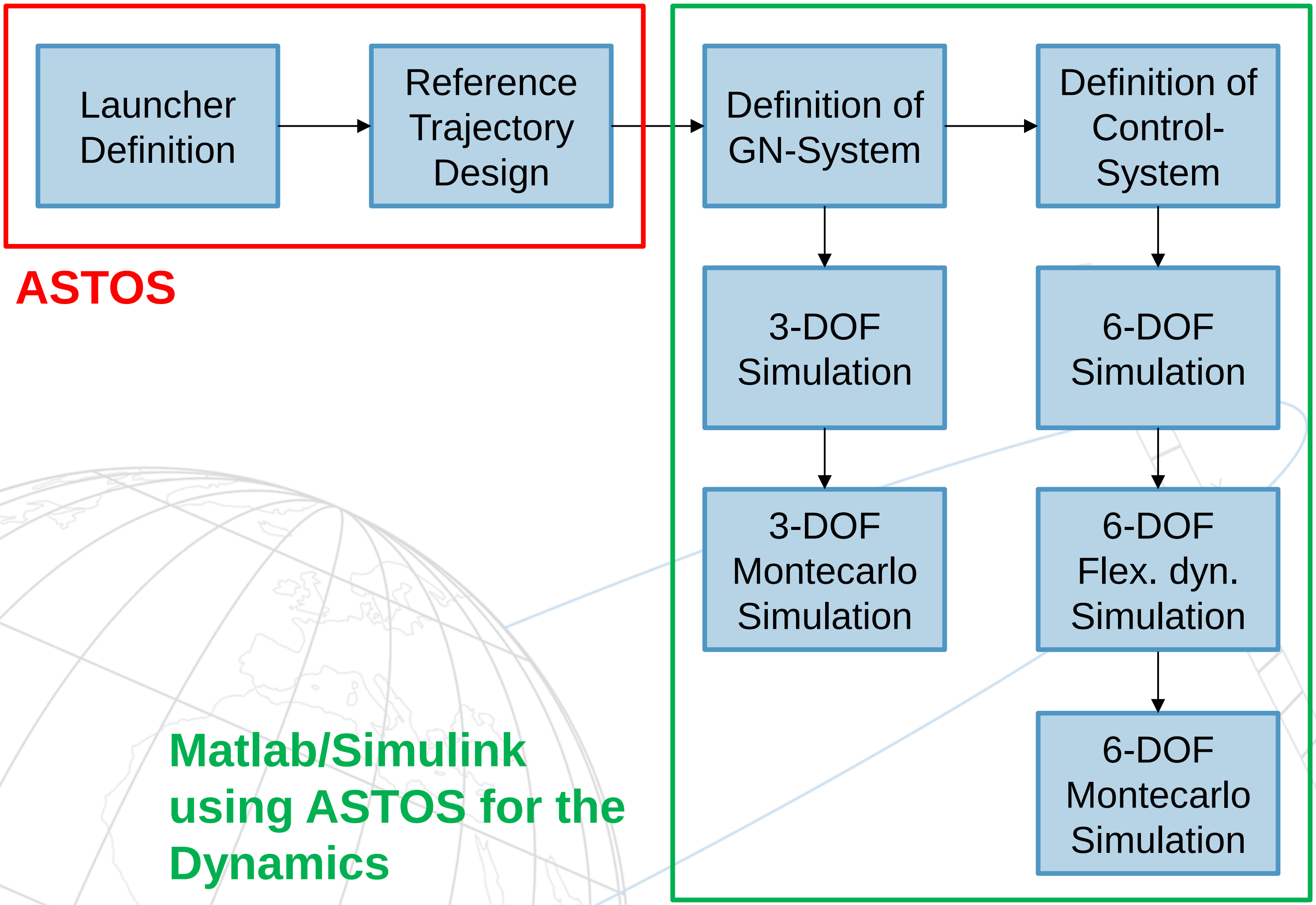
- DCAP Background
  - Is a multi-body software like ADAMS, predecessor of SIMPACK
  - ESA development with TAS-I since 1980-ies
  - Since 2014 Astos Solutions continuous the development of DCAP
- ASTOS-DCAP coupling
  - Full integrated in ASTOS scenario with small additional effort
  - Focus on orbit dynamics
  - Definition of hinges, sensors, actuators, devices
  - Modelling of mechanical devices
  - Use of NASTRAN FE-models or of internal beam model for flexibility
  - Modelling of linear propellant sloshing models
  - Definition of multi-body structures like robotic arm
  - Computation of contact dynamics
- ASTOS linearized flexible dynamics
  - Based on DCAP Mode Shape export

ASTOS-DCAP Examples

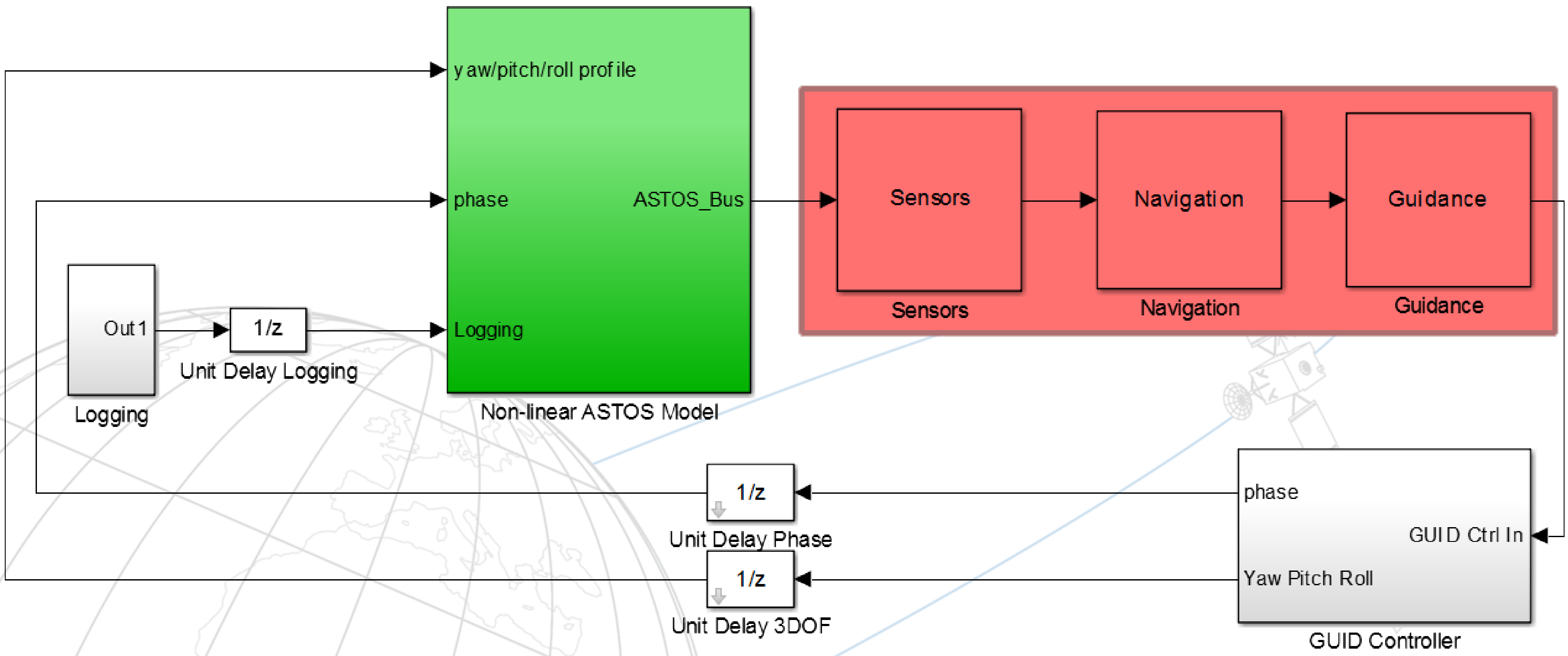
Added value of DCAP coupled with ASTOS

- Solar panel
  - Flexible dynamics of large structures
- Robotic Arm
  - Flexible bodies and joint definition using hinges
- Contact dynamics
  - Detection of collisions and modelling of contact dynamics
- Stage separation
  - Definition of spring/damper devices modelling the separation impulse
- Propellant sloshing
  - Modelling of sloshing using spring/damper and pendulum models
- GNC
  - Consideration of flexible body dynamics for controller design

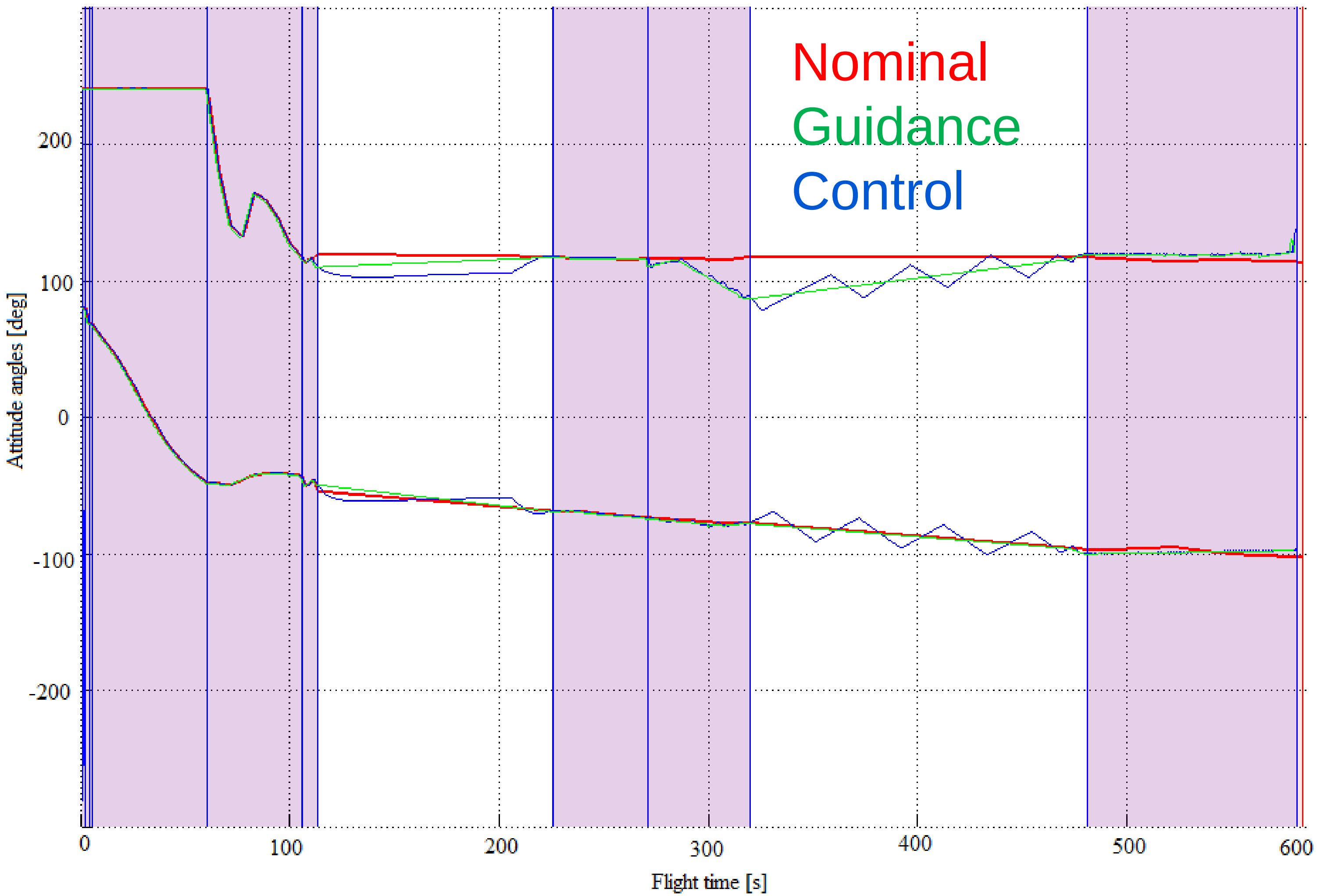
GNC Workflow



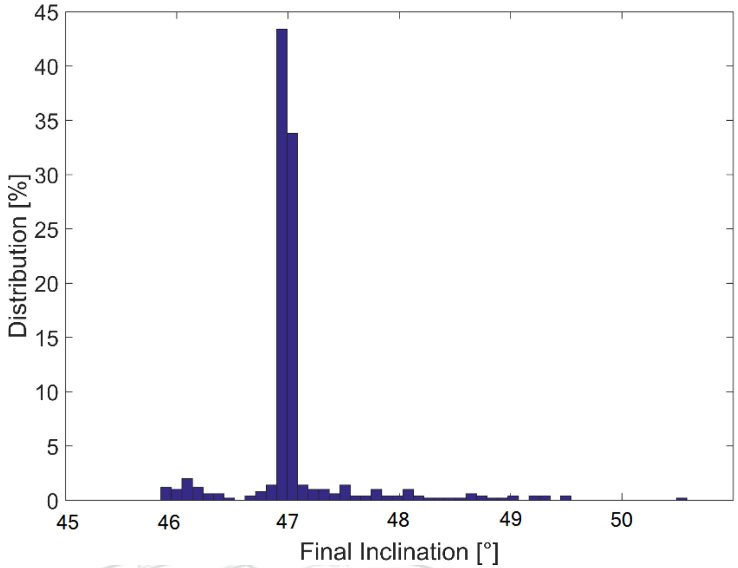
Definition of GNC-System

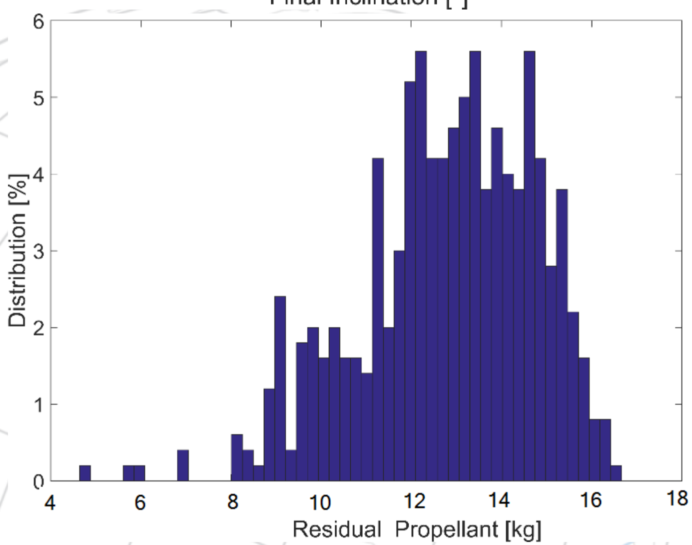


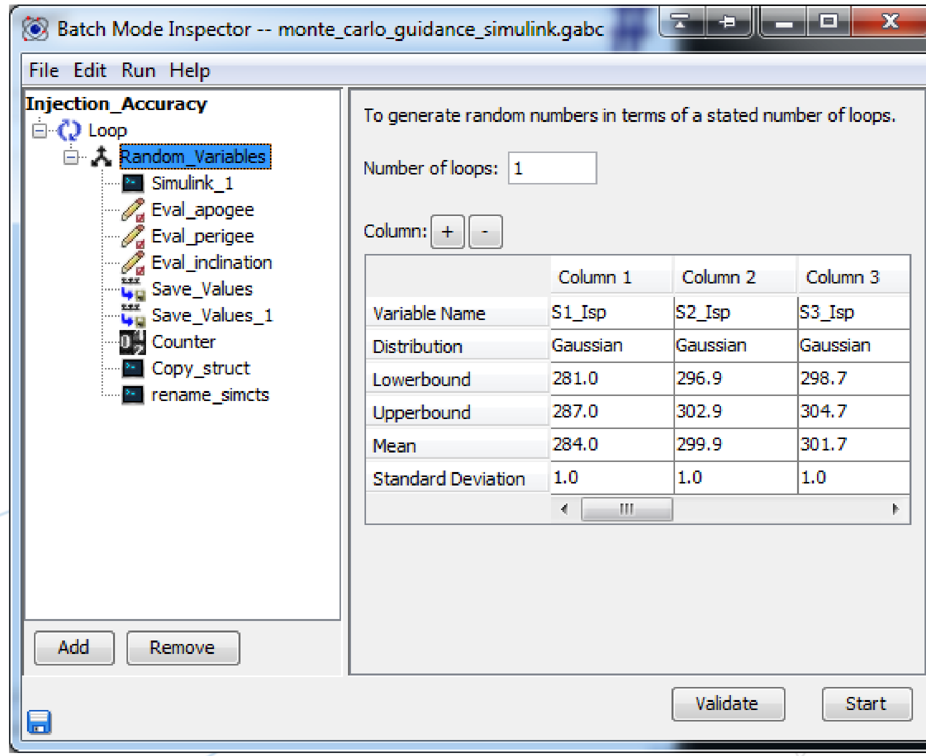
GNC Output Example



GNC Monte Carlo







GNC Lessons Learnt

- Guidance and control requirements should be considered during the creation of the reference trajectory:
  - Attitude angle rates
  - Stiff maneuvers (e.g. impact of empty stages)
  - Misalignment compensation

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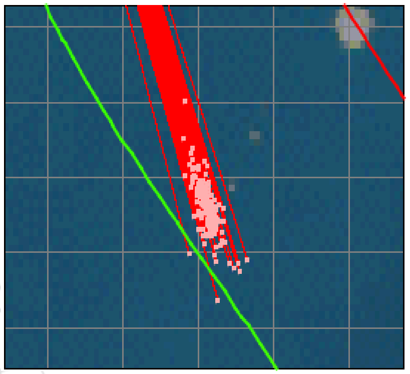
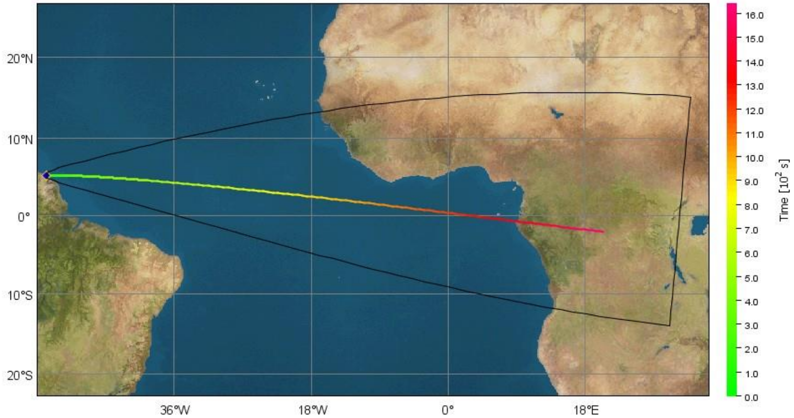
SAFETY ANALYSIS

Risk Assessment

- Launch & reentry risk assessment
- Object-oriented modelling of the vehicle based on primitives
- Explosion and fragmentation tree modelling
- Multiple explosion & fragmentation triggers (e.g. temperature, altitude, loads)



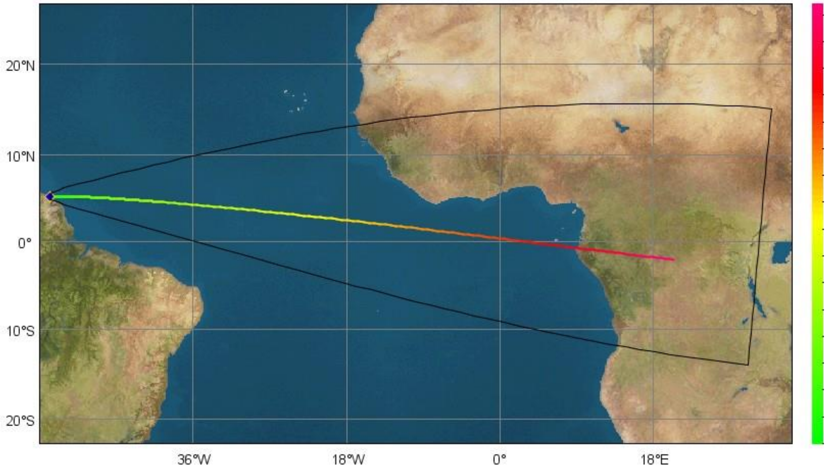
- Provides on-ground, air traffic as well as ship traffic related risk figures (casualty & fatality probability)
- Launch risk assessment considers blast in case of explosions
- Launch analysis calculates the flight corridor according to FAA requirements



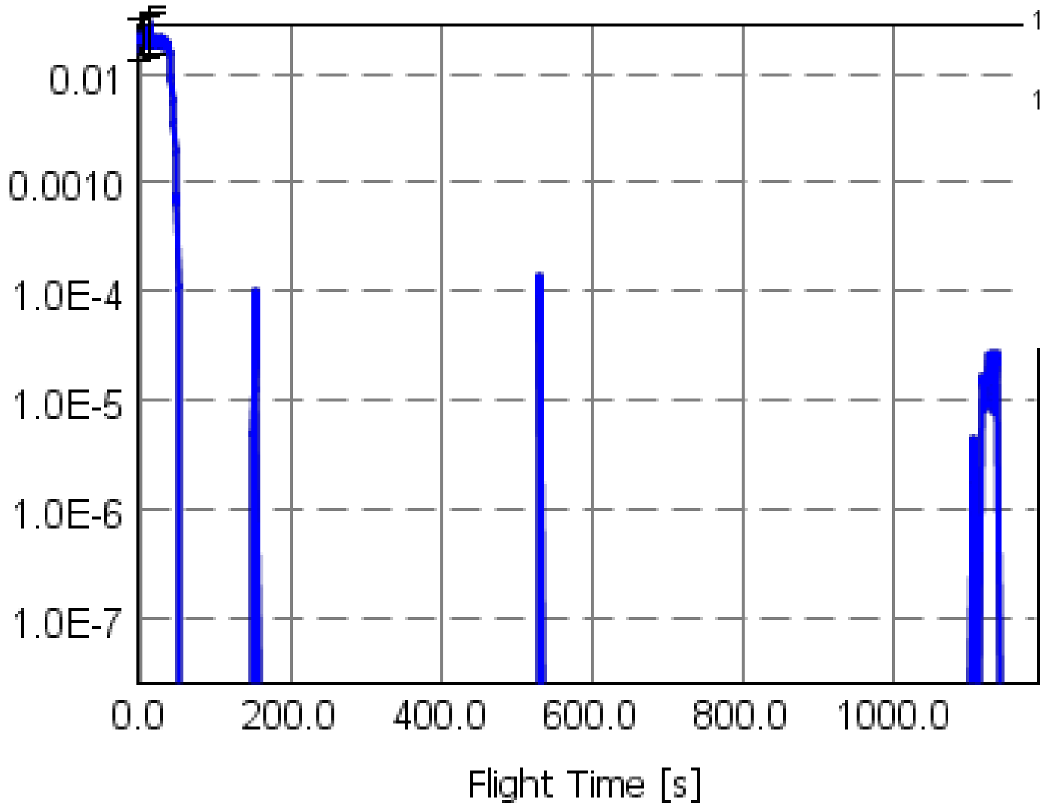
Launch Safety Analysis

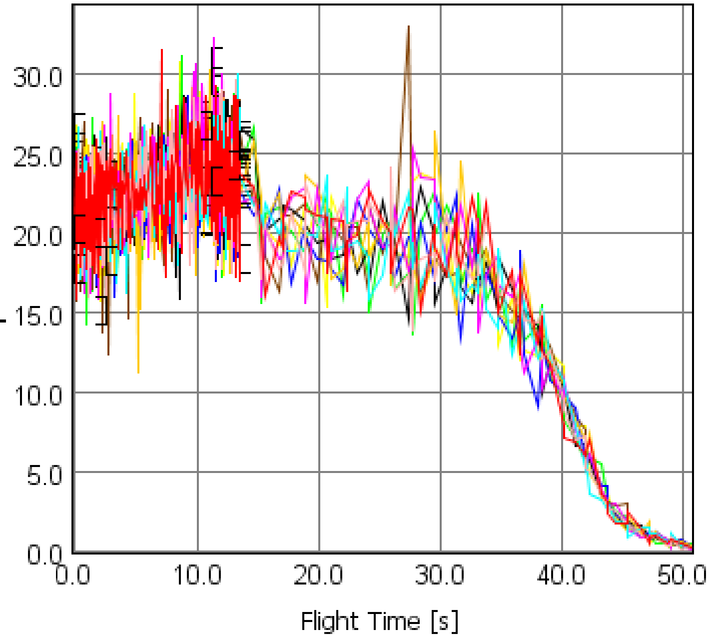
It estimates the risk of casualty and fatality for launchers in case of failure (explosion) during the ascent trajectory.

It computes the flight corridor according to the FAA definition and it estimates the envelope of the destruction area caused by the shockwave generated by an explosion.



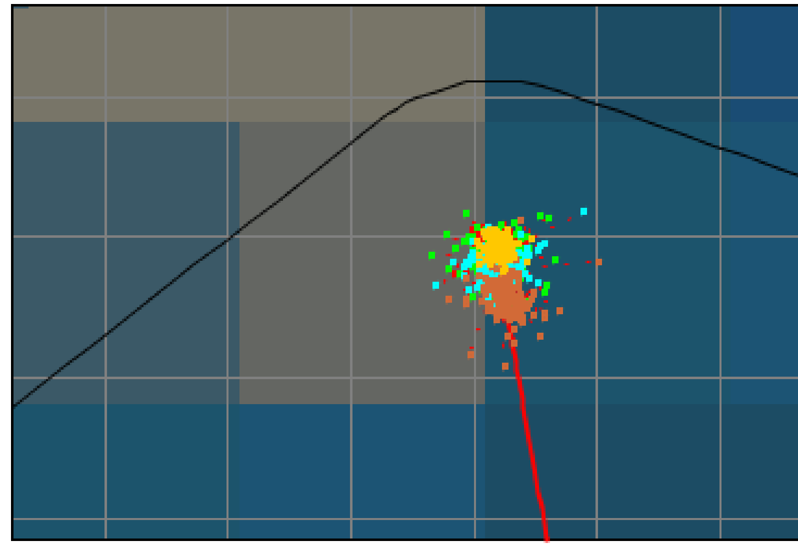
Launch safety example

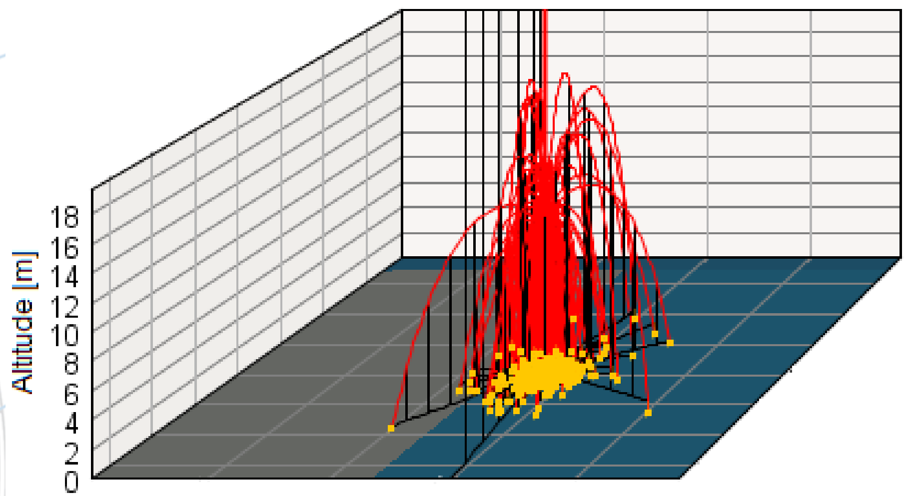




Explosion first seconds

- Black line is FAA flight corridor.
- Yellow dots explosion at lift-off,
- red dots at end of vertical phase,
- green dots at end of pitch-over,
- cyan dots at end of pitch-constant phase,
- brown dots during gravity turn phase.





Summary

- The implementation of new modules in ASTOS has improved the capability of the software to answer the need of aerospace engineers during the preliminary design of the vehicle.
- The funding by ESA through multi-year projects made possible a comprehensive implementation in the most important areas of the vehicle design: structure, propulsion and aerodynamics.
- The inclusion of interfaces to Matlab/Simulink, ODIN, DCAP and RPA added the missing analysis capability. Advanced safety analyses are present in the software.
- ASTOS is therefore an efficient simulation infrastructure to design launchers up to the phase B1.
- This software is commercially available to all interested entities worldwide.

Thank you!

Please visit our booth to get more information.