Analysis, Simulation and Trajectory optimisation for Space Scenarios (ASTOS) Market-Oriented Activities

Space Engineering and Technology Final Presentation Days,
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Outline

- ASTOS
- New features
- ASTOS for space transportation
  - Vehicle design
  - GNC sizing
  - Safety analysis
- Summary

ASTOS From Past to Future

Past – Since 1989 up to ASTOS 7

- „I know ASTOS as a trajectory optimization tool“

Present – ASTOS 8.0

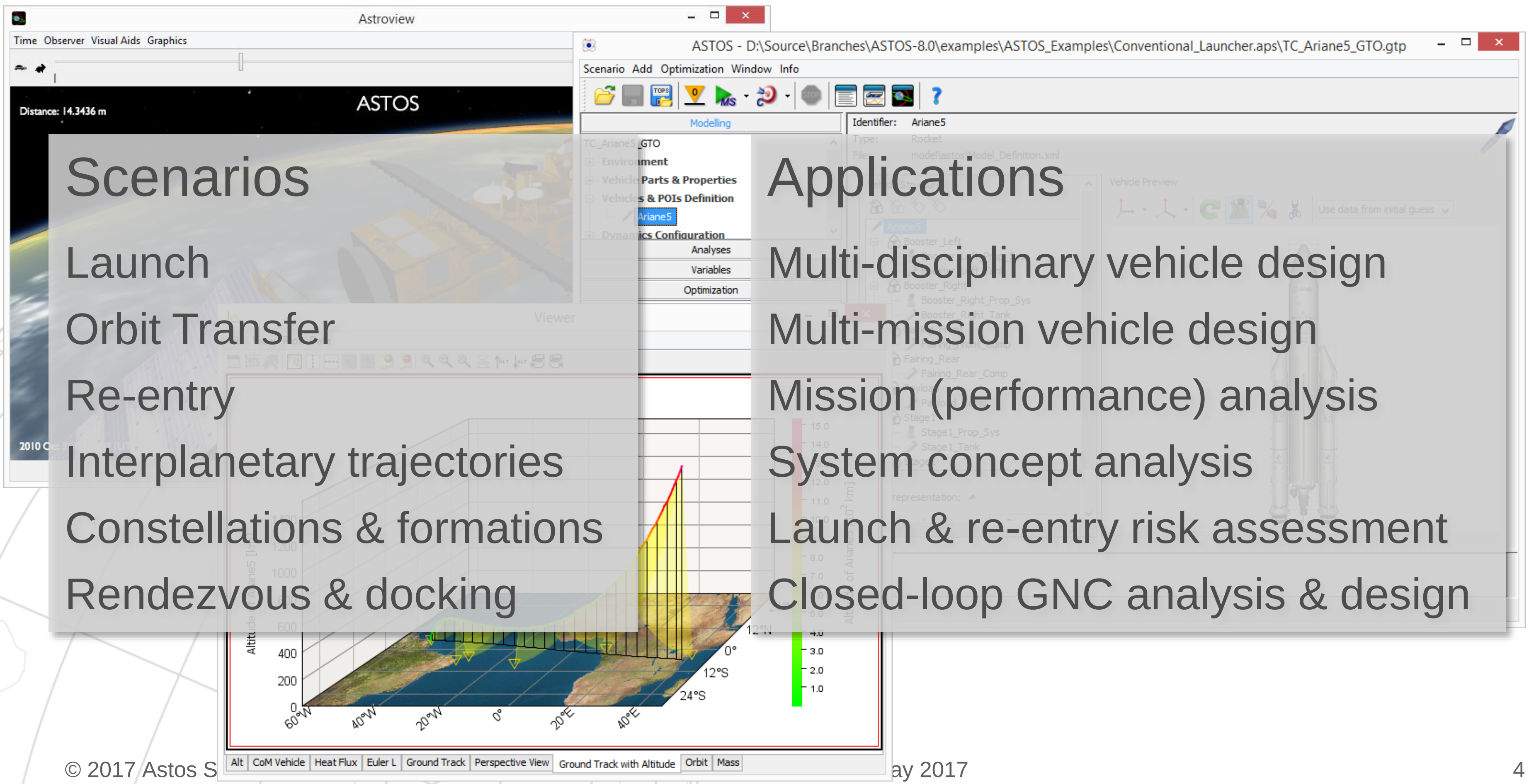
- Launcher Design up to Phase B
- Mission Analysis
- GNC Design & Analysis
- Functional Engineering Simulation

Near future – ASTOS 9

- System Concept Simulation

ASTOS – An Overview

ASTOS – **A**nalysis, **S**imulation and **T**rajectory **O**ptimization Software for **S**pace Applications



Scenarios

- Launch
- Orbit Transfer
- Re-entry
- Interplanetary trajectories
- Constellations & formations
- Rendezvous & docking

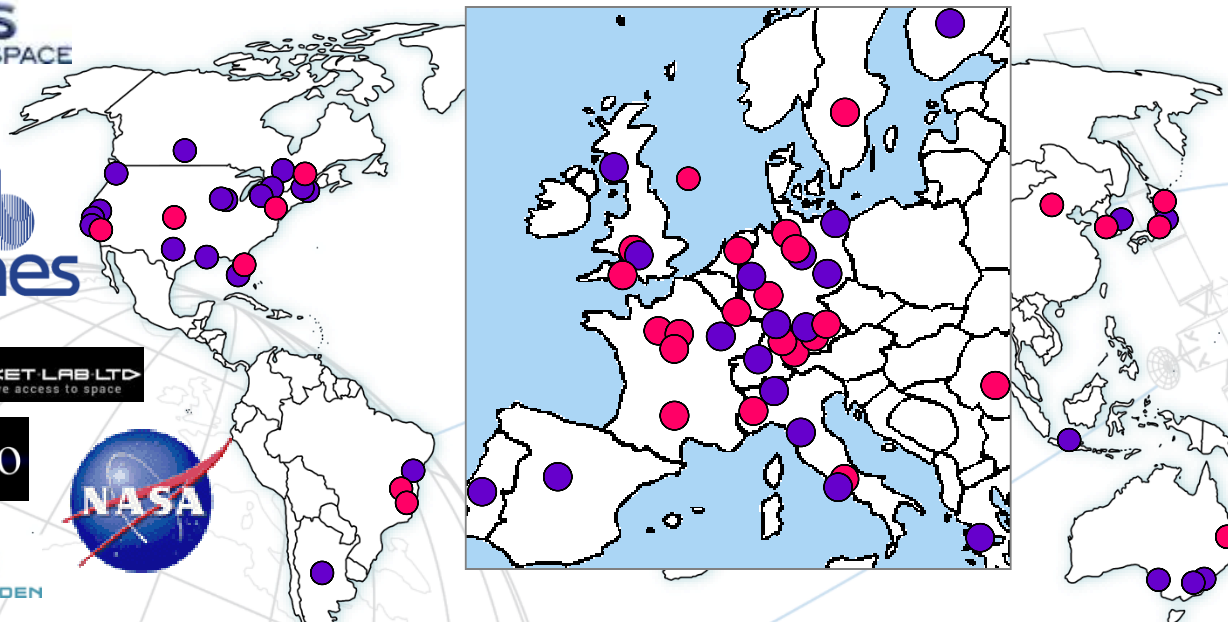
Applications

- Multi-disciplinary vehicle design
- Multi-mission vehicle design
- Mission (performance) analysis
- System concept analysis
- Launch & re-entry risk assessment
- Closed-loop GNC analysis & design

Customers

Industry & Agencies

INCAS
ANDØYA SPACE CENTER
esa ESTEC
dstl
SES ASTRA
AIRBUS DEFENCE & SPACE
ThalesAlenia Space
CIRA
cnes
ROCKET LAB LTD Innovative access to space
FiatAvio
NASA
OHB SWEDEN
ATK
DLR
IAE
DSTO AU
Explore the Engineering Edge IHI
TRIPOLI ROCKETRY ASSOCIATION, INC.
IAI
ATI ADVANCED TECHNOLOGY INSTITUTE



Universities

Europe

Berlin
Stuttgart
München
Bremen
Athens
Greifswald
FH Aachen
Naples
Cranfield
Glasgow
Madrid
ETH Zürich
Dresden
Brussels
TU Delft
Reading
West England
Bordeaux
Zaragoza
Pisa

North America

California
Stanford
Seattle
MIT
Illinois
Austin, Texas
Carleton, Qu
Edmonton, Al
Toronto
Minneapolis
Maryland
Iowa State
UCLA Los Angeles
Purdue
Cincinnati
Pennsylvania State
Ryerson

South America

Cordoba, Ar
Minas Gerais, Br

Asia

Yonsei, Seoul, Kr
Nanjing
Yogyakarta

Australia/NZ

Sydney
Canberra
Adelaide
Auckland
Canterbury

Launcher Activities

- Origin FESTIP (ESA funded ALTOS development with MBB/DLR)
- ESA’s Mars Ascent Vehicle design optimization
- VEGA, support of TEC-ECN and ASI/ESRIN
- **Micro-Launcher design since 2003**
- **Small launcher design** for US and Japanese companies
- RLV concepts: Fly-back Booster, Hopper, Skylon, SpaceLiner
- **NELS**, subcontract to OHB
- Support of German industry related to Ariane 6
- German launcher studies, e.g. ANGELA
- Launcher performance for ESA activities: G2G, VEGA for Telecom, etc
- **Support to IAE** (Brazil) and DLR/MORABA for VLM/VLS, Shefex II
- 3rd generation **KSLV**, support to KARI
- Support to nano/micro launcher activities worldwide, e.g. **Rocket Labs**
- Technology development activities: CDO, MDO, LGSST, LAUMBS
- Support of STERN activities
- ASTOS is accepted for FAA Class 3 amateur rocket activities

Astos Solutions

NEW FEATURES

New Features of ASTOS 9

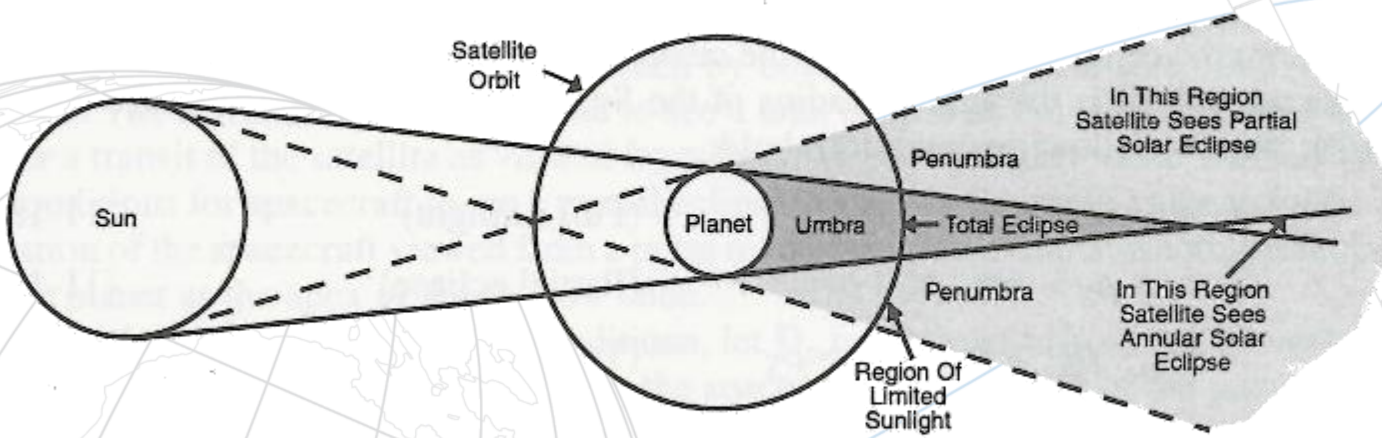
- System concept analysis for power, thermal control and data management aspects
- Completed mission analysis capabilities required for Earth observation missions
- Integrated CAD import & texturing tool
- Wizards to improve usability and to increase the user performance
- Further small extensions like
  - Initial state definition as Lissajous or HALO orbit
  - Propagation as circular restricted three-body problem
  - Consideration of relativistic effects and solar-radiation pressure
  - Injection and correction maneuvers for interplanetary trajectories
  - Pork-chop plots

Operational Life-Time Prediction

- The operational life-time is limited by the fuel budget.
- Fuel consumption is considered with respect to these aspects
  - Orbital correction maneuvers (e.g. decay and GEO station keeping)
  - Collision avoidance maneuvers (based on debris fluxes obtained e.g. by means of the ESA MASTER software)
  - End-of-life disposal (de-orbit or transfer into graveyard orbit)
  - Attitude control (desaturation of wheels)
  - Injection accuracy
- The operational lifetime prediction analysis provides
  - Operational lifetime
  - Total ΔV and fuel requirements for each type of manoeuvre

Eclipse Analysis

- Eclipse conditions evaluated, reporting percentage of non-visible Sun surface
- Duration of light, umbra and penumbra conditions
- Minimum light duration and maximum umbra duration



Interplanetary Trajectories

Phase Conditions

- **Plane Intersection**: to change orbit plane required for escape burn
- **Injection**: for phasing of optimal escape burn
- **Sphere of Influence**: to switch central body

Initial Manoeuvres

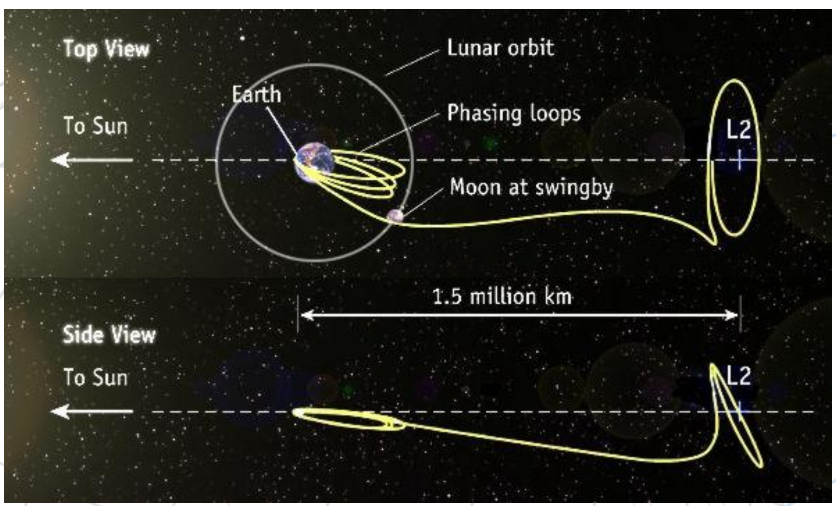
- **Transfer Plane Injection**: burn changing orbit plane required for escape
- **Interplanetary Injection**: escape burn
- **Deep Space Manoeuvre**: correction of transfer considering arrival altitude

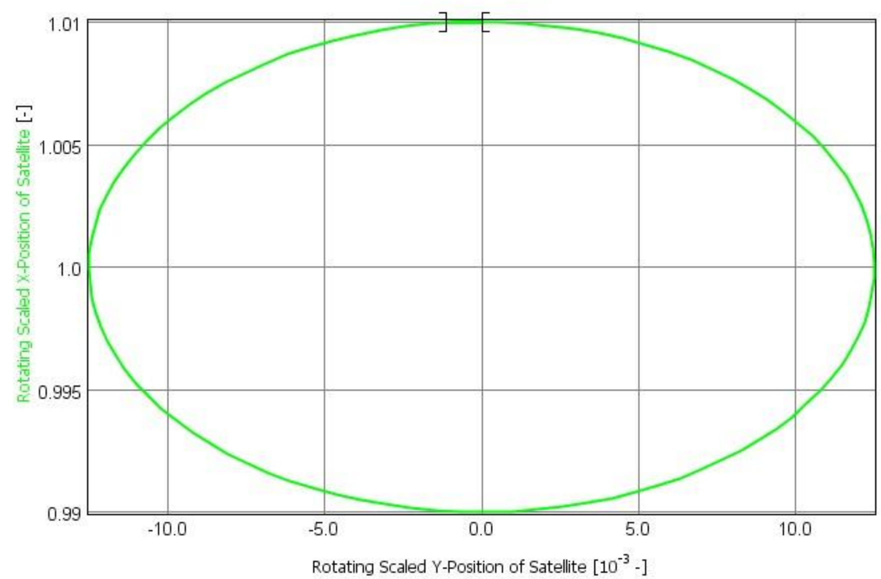
Analysis – Pork Chop Plot

- User input: start date, end date/duration, celestial bodies
- Lambert solver
- Output: aux functions for pork chop plot (start & arrival date, transfer duration, delta-v)

Lagrange Point Orbits

- A Halo orbit can be computed as initial state around L1, L2 or L3 of the main 3-body problems of our solar system
- CR3BP equations of motion can be used to propagate and 3BP trajectory (e.g. Halo orbit, escaping orbit, etc)





Power System Model

- The following dedicated power generation and management models have been added:
  - Battery
  - Solar Generator
  - Power Control and Distribution Unit (PCDU)
- Each actuator, vehicle component or sensor can be a consumer with specified electrical power (optional input)
- PCDUs specify multiple ciruits each with different voltage
- Solar panels consider angle towards the sun, eclipses and temperature to calculate generated electrical power
- Batteries are charged and discharged based on available/required electrical current within a PCDU

Thermal Model

- Model provides temperature evolution of each thermal node
- The model considers:
  - Heat transfer between nodes
  - Irradiation and Emission for dedicated surface elements
- Surface elements are defined as planar and can model any number of thermal nodes
- Thermal nodes are available for every actuator, component or sensor (optional)
- User-defined connections between thermal nodes (defined by thermal resistance)
- Thermal nodes are defined by specific heat capacity, initial temperature and the mass of the corresponding equipment

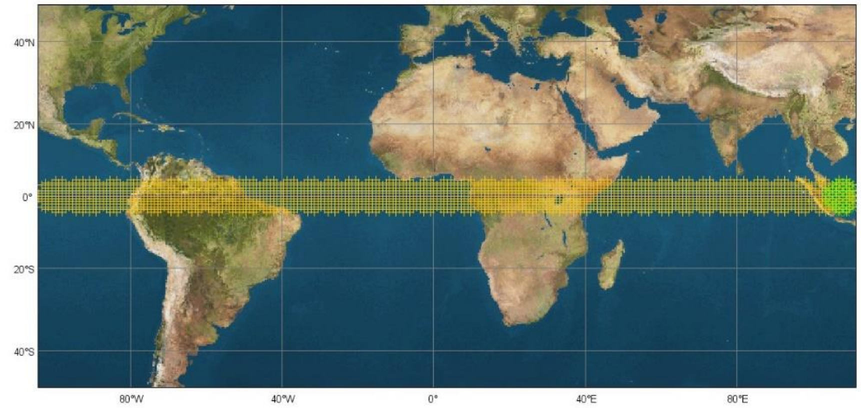
Data model

- Modelling of radio-transmission, data generation and data storage
- Dedicated model: data buffer with user-defined capacity
- Each equipment block can be defined as data source (housekeeping and payload data)
- Data is transmitted to other vehicles and ground stations by specifing communication partners for sensors
- Data busses are user-defined connections containing data sources, data storage and transmitters

Coverage Analysis

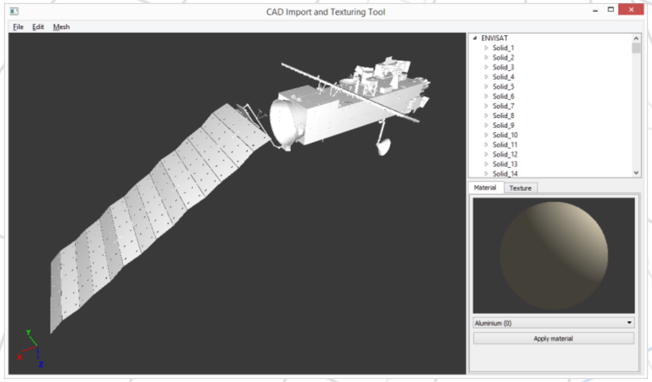
Flexible Analysis able to consider customizable combinations of the following conditions:

- Visibility from an orbital sensor to an area/point on ground (coverage checked for each pixel)
- Link between Tx and Rx in space or on ground
- Link via a set of relay satellites (e.g. constellation)
- Latitude scaled pixelization or Hierarchical Equal Area Iso-Latitude Pixelization



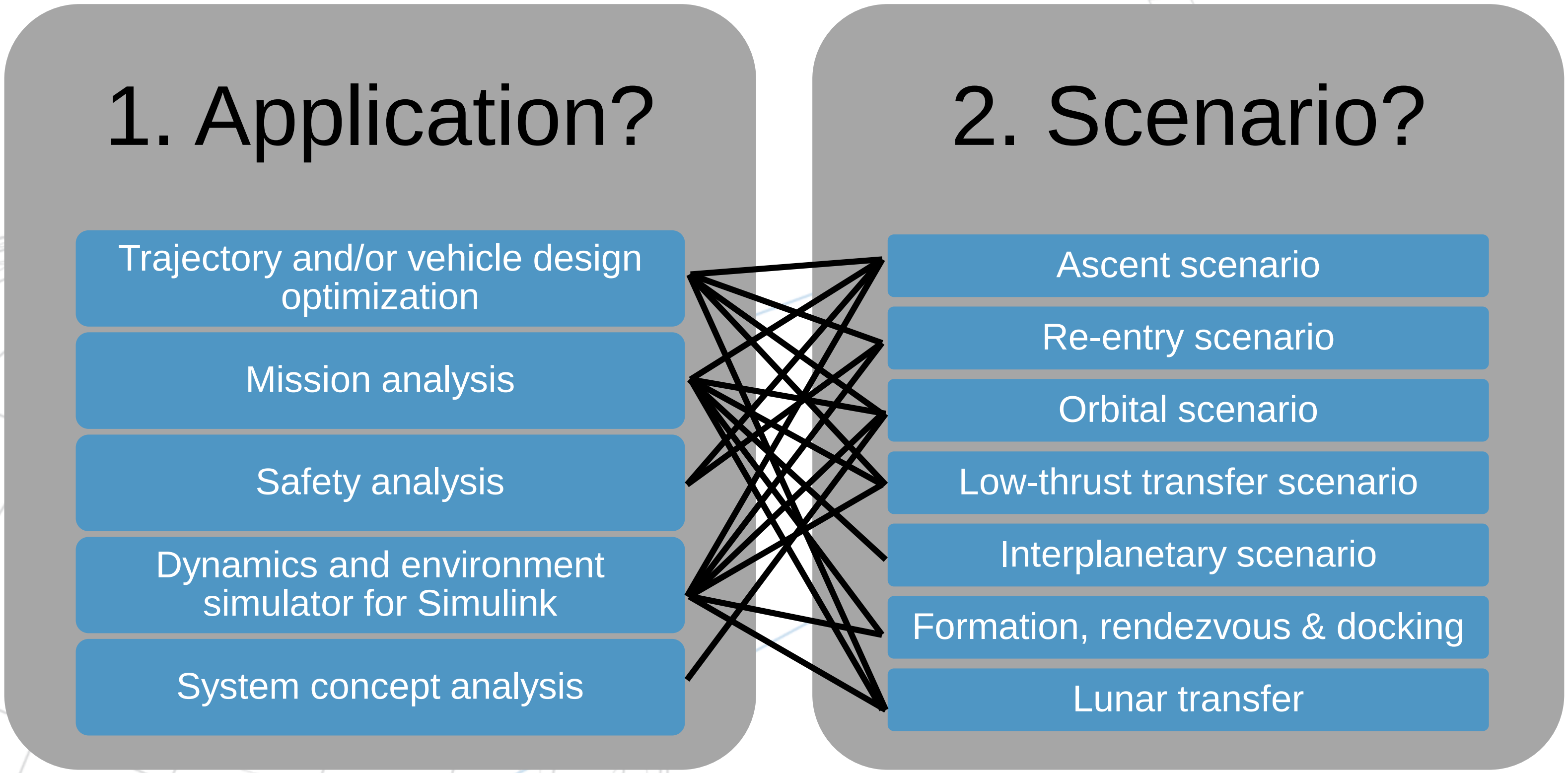
Texture Mapping Tool

- Import of Wavefront OBJ and STEP files (AP 203, 209, 214)
- Export of Wavefront OBJ files
- Automatic texture projection based on object extends and texture distortion reduction
- Manual planar, spherical and cylindrical projection
- Predefined materials consider physical extends
- Logo decals on top of materials, including textured materials



Wizard

- The wizard questions guide the user towards the definition of his/her application and scenario
- Modification of exisiting scenarios is supported as well

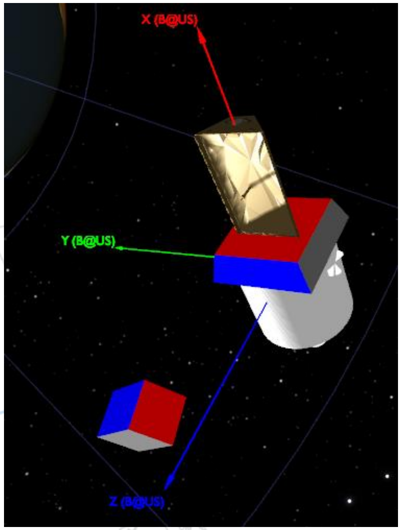


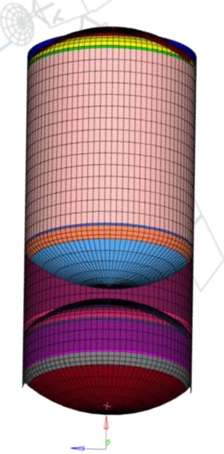
Astos Solutions

ASTOS FOR SPACE TRANSPORTATION

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

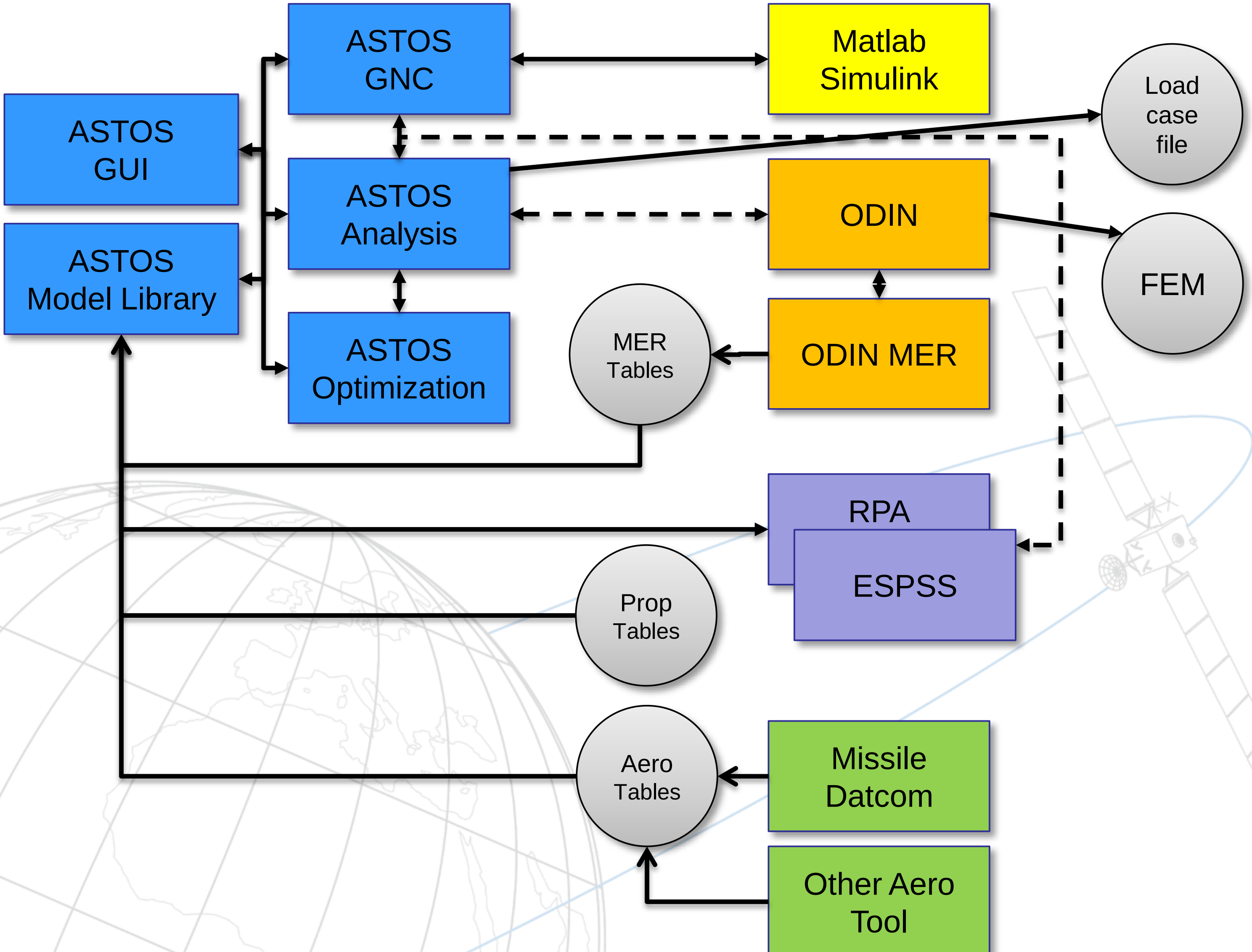




Multidisciplinary Design Optimization

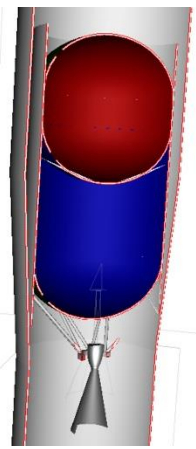
- Fast aerodynamics computation
  - SOSE (surface inclination method)
  - Missile Datcom for launchers
- Propulsion system
  - Chemical equilibrium in chamber based on RPA
  - Regression of efficiency and engine mass for various engine and propellant types
  - Preliminary cycle analysis
  - Thermal analysis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

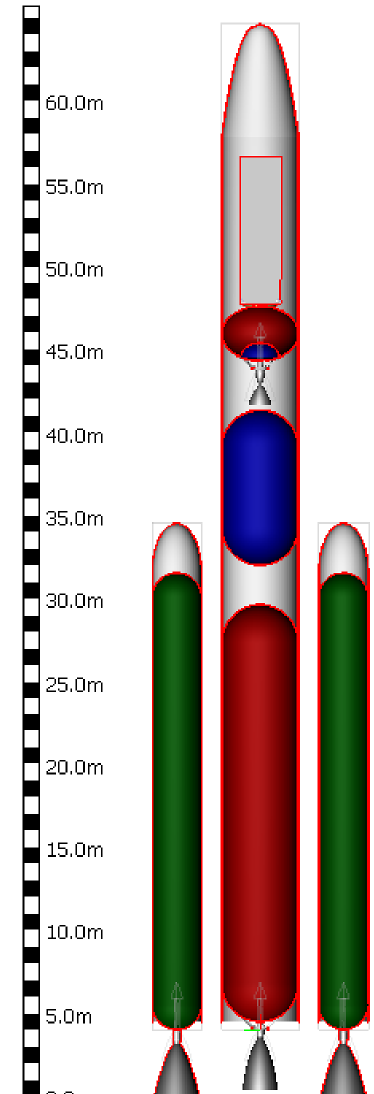
MDO Architecture



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

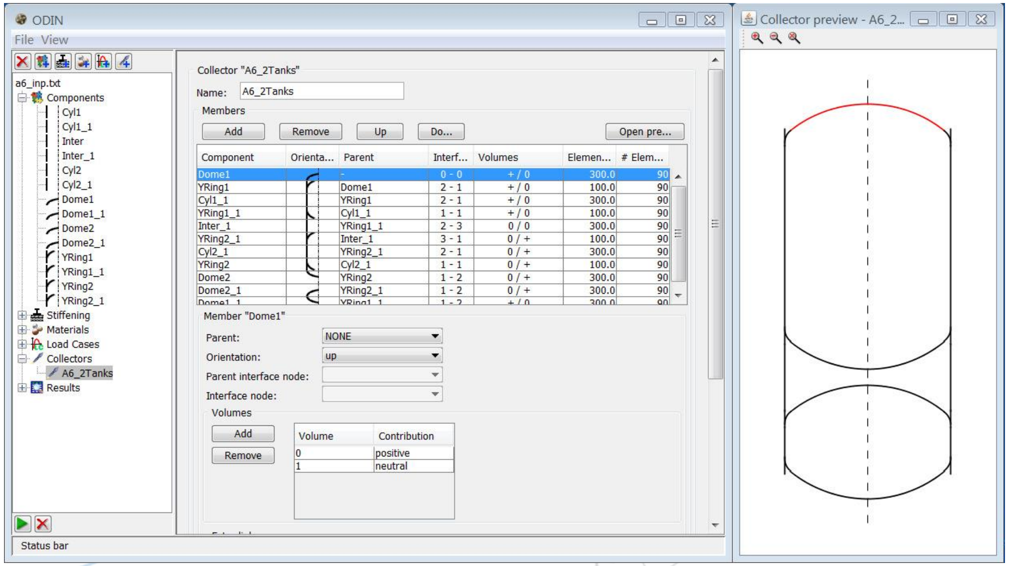


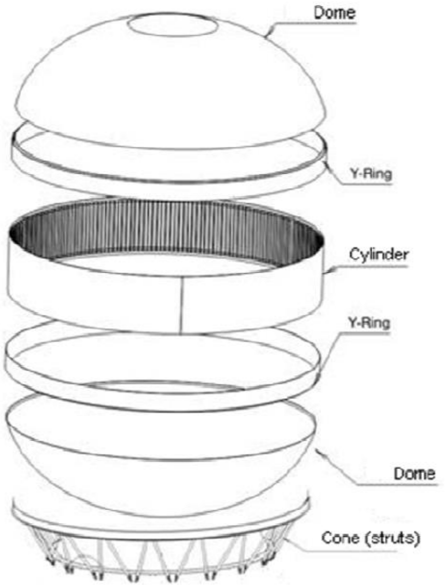


=> Computation of COM and MOI
assuming shell structures and tank filling

ODIN

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

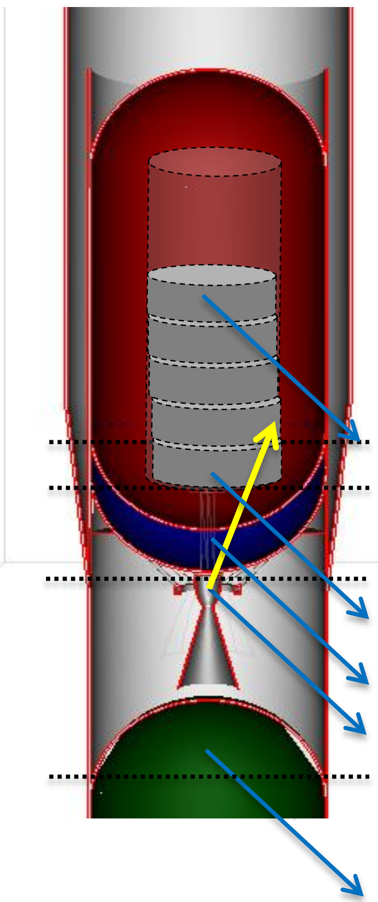




- Structural mass optimization based on ODIN
- Mass regression based on
  - Geometry
  - Material & stiffening concept
  - Dimensioning load case

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

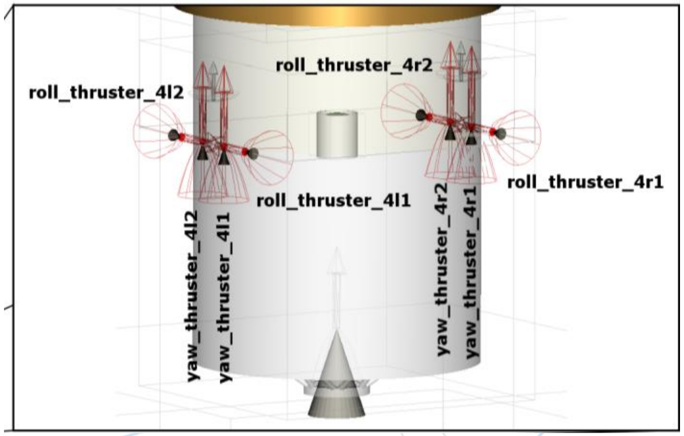
- Tables
  - Stage dimensions and masses
  - Final Orbit
  - Key trajectory events comprising time points of maximum loads & phases and dimensioning line loads
  - Table of substructures with stiffening concept, dimensions, mass and comparison with ODIN mass

Automatic template creation and completion!

Space Transportation Launcher GNC

GNC Design

- LGSST project, ESA TRP
- GNC algorithms under Simulink
- DCAP 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

GNC Design & Analysis

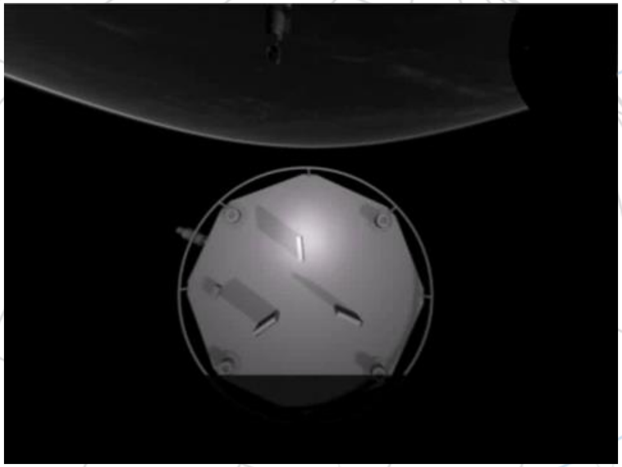
Conceptual Design

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

Preliminary/Detailed Design

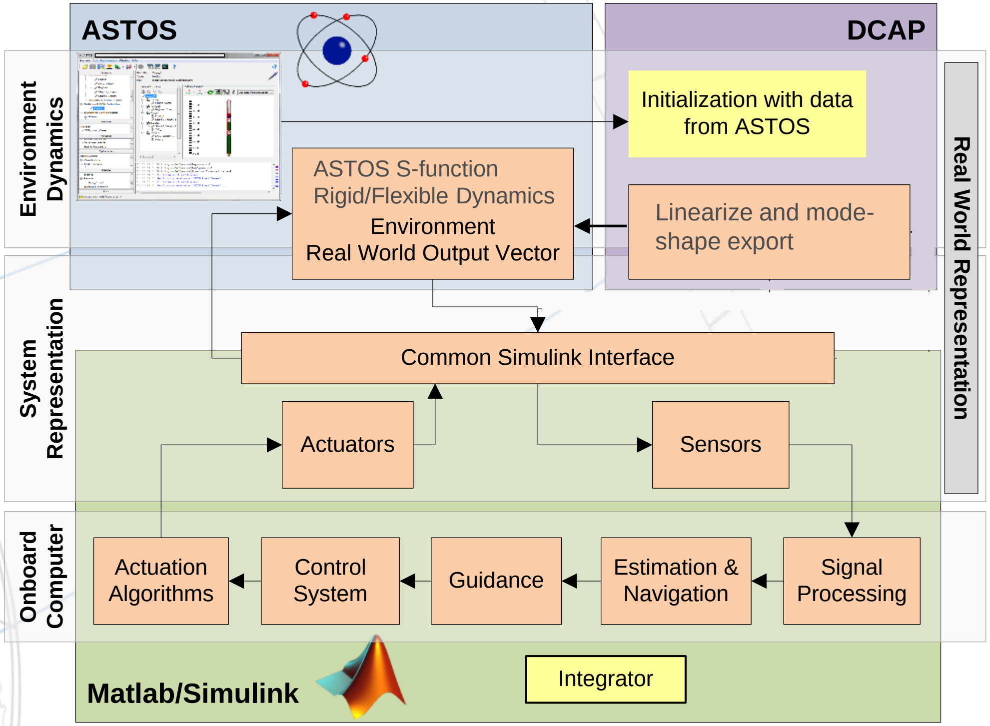
- Stepwise switch to Simulink

> ➢ Navigation extension with Camera Simulator



Advanced Features

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

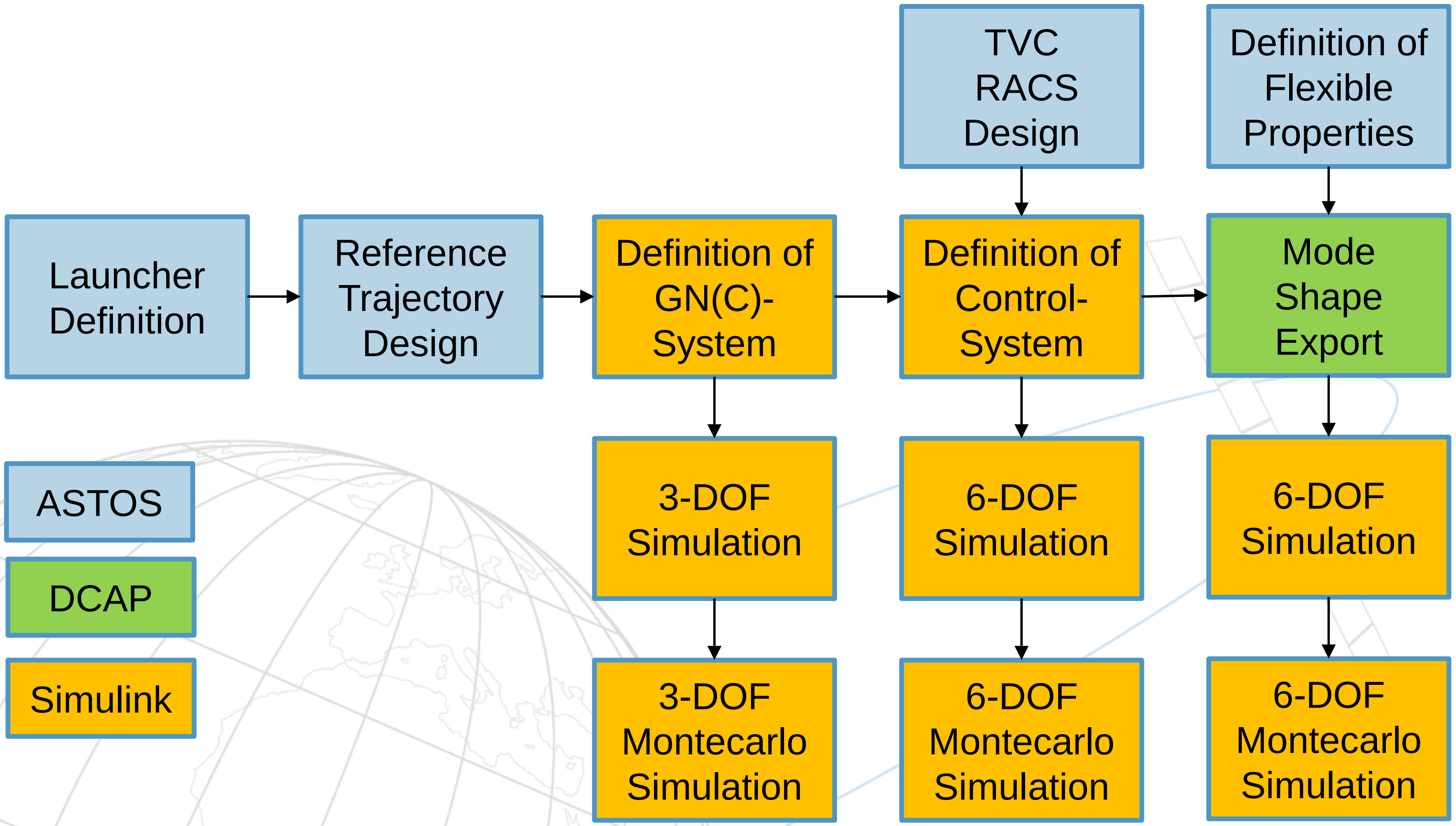


ASTOS-DCAP Examples

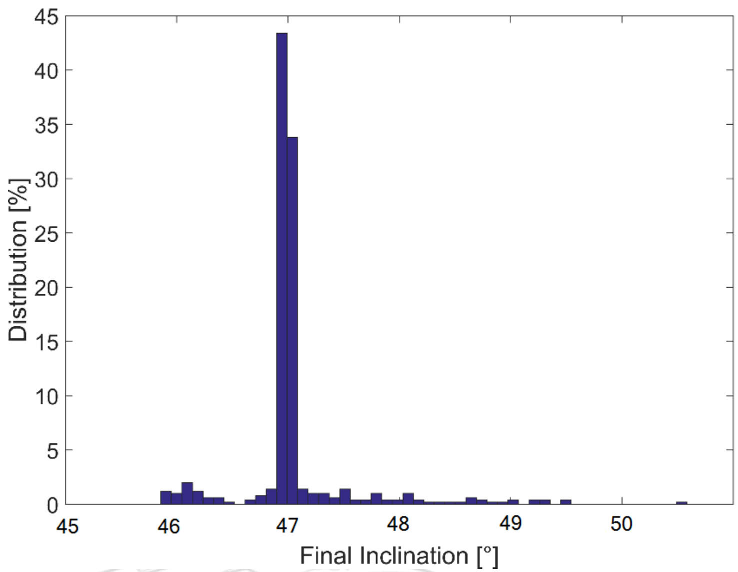
Added value of DCAP coupled with ASTOS

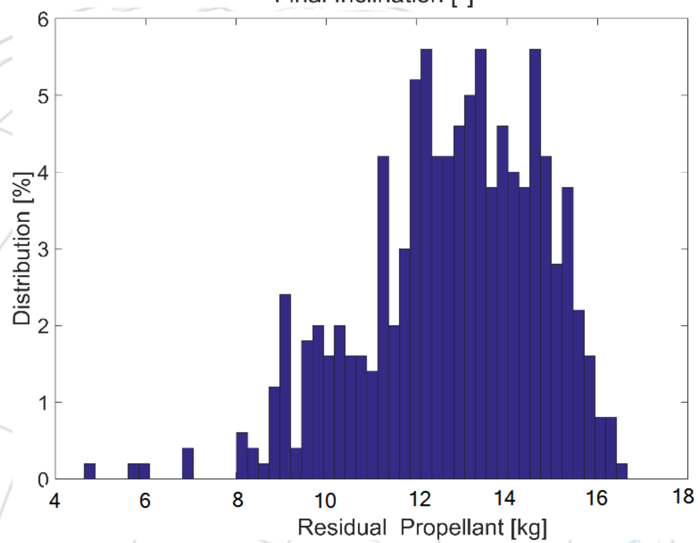
- Solar panel
  - Flexible dynamics of large structures
- Robotic Arm
  - Flexible bodies and joint definition using hinges
- Contact dynamics
  - Detection of collisions and modelling of contact dynamics
- Stage separation
  - Definition of spring/damper devices modelling the separation impulse
- Propellant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

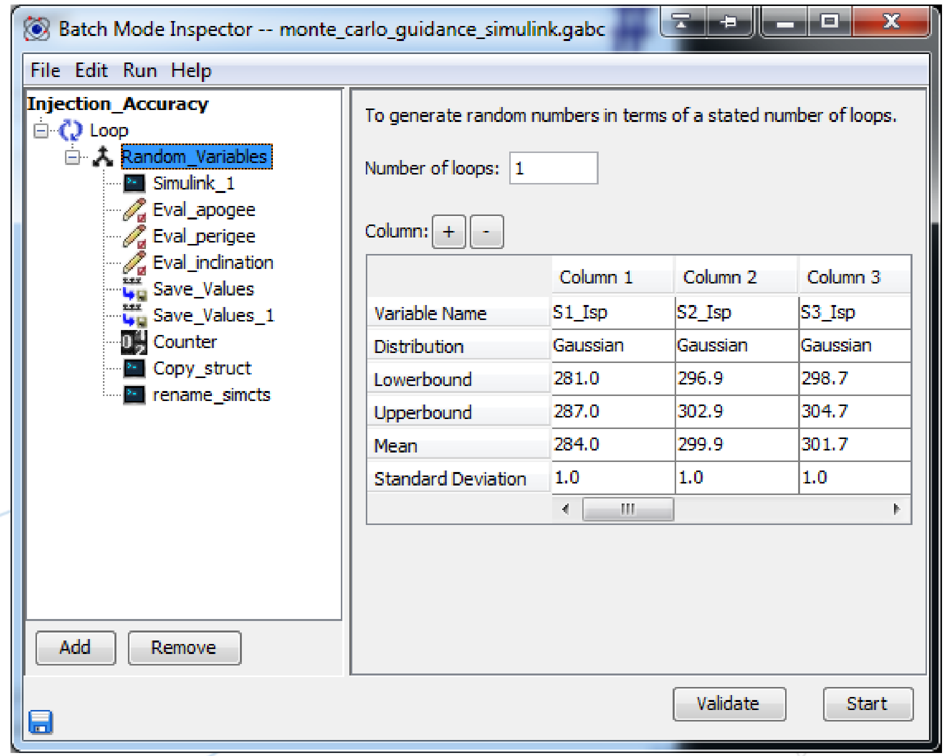
Workflow – GNC Sizing



GNC Monte Carlo

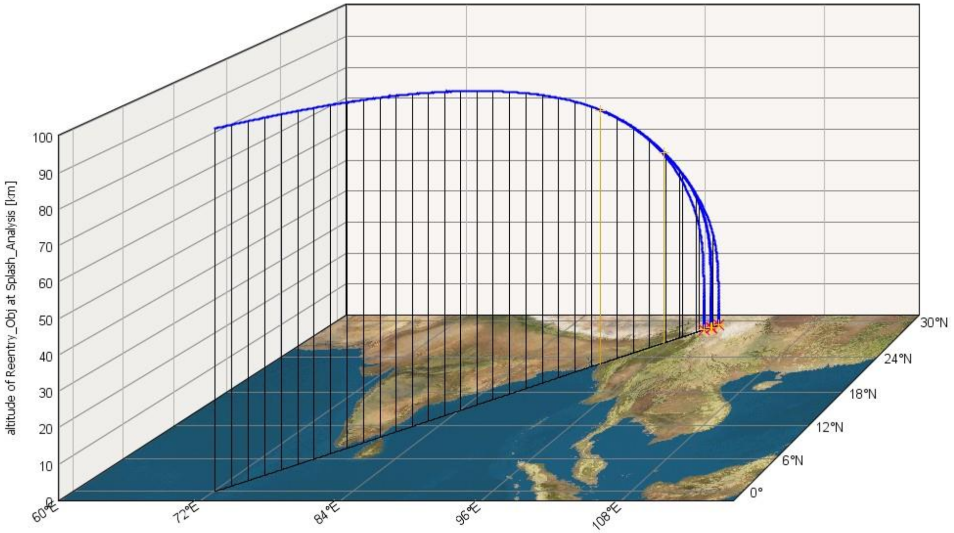






Risk Assessment

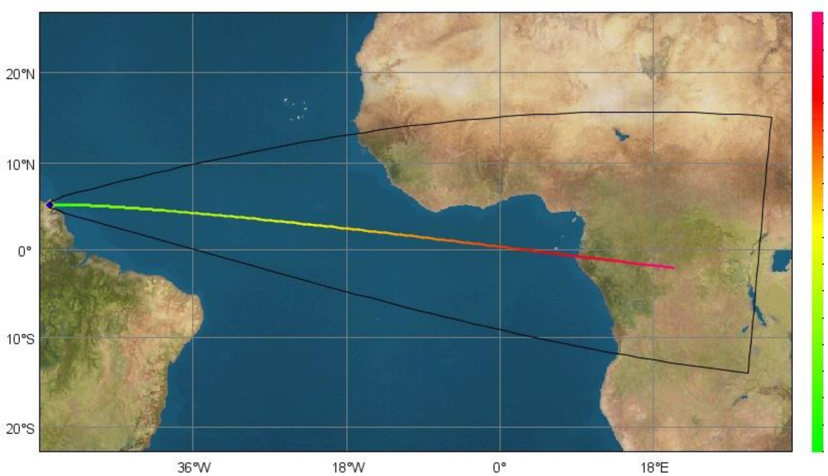
- Launch & reentry risk assessment
- Object-oriented modelling of the vehicle based on primitives
- Explosion and fragmentation tree modelling
- Multiple explosion & fragmentation triggers (e.g. temperature, altitude, loads)
- Provides on-ground, air traffic as well as ship traffic related risk figures (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

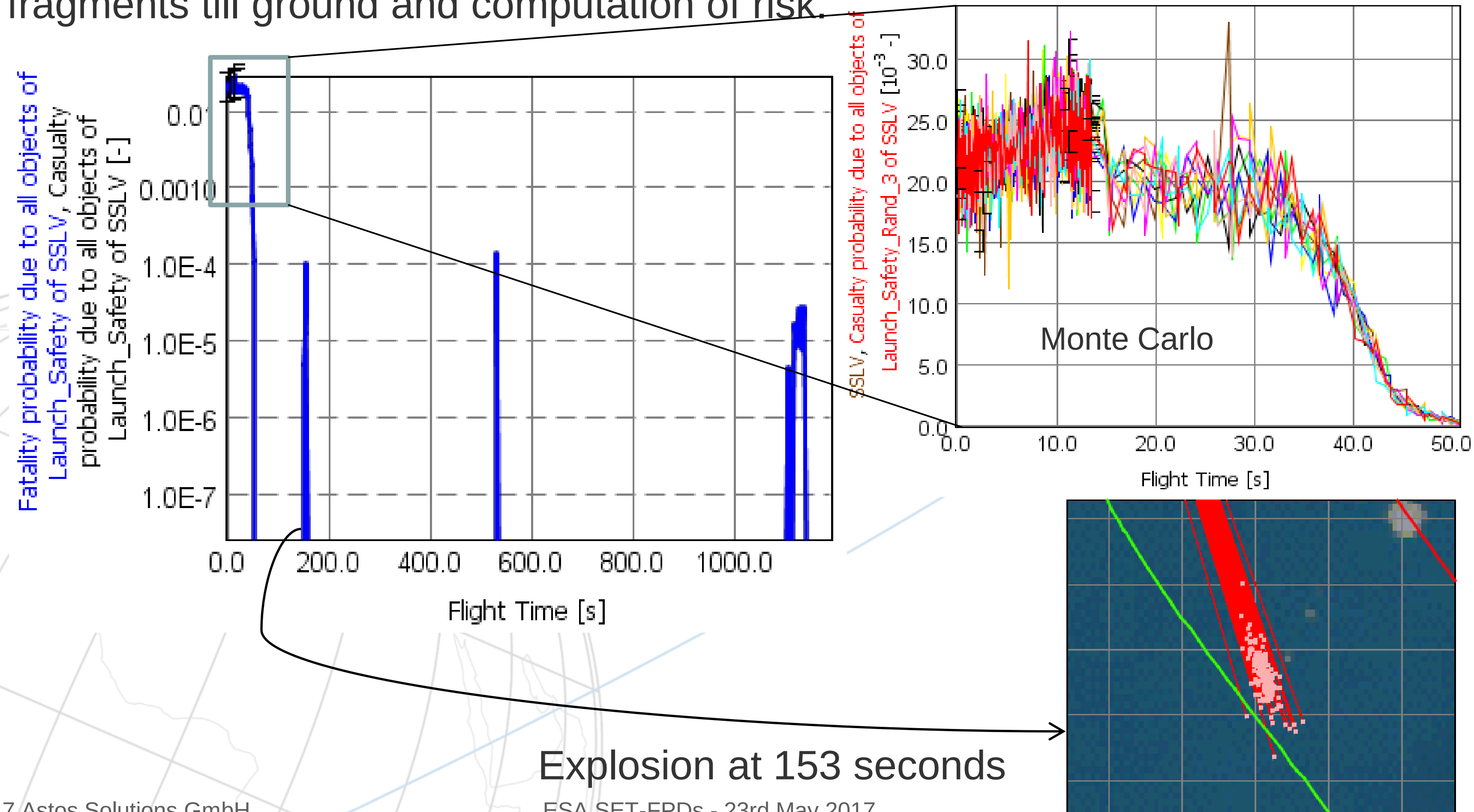
It estimates the risk of casualty and fatality for launchers in case of failure (explosion) during the ascent trajectory.

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.



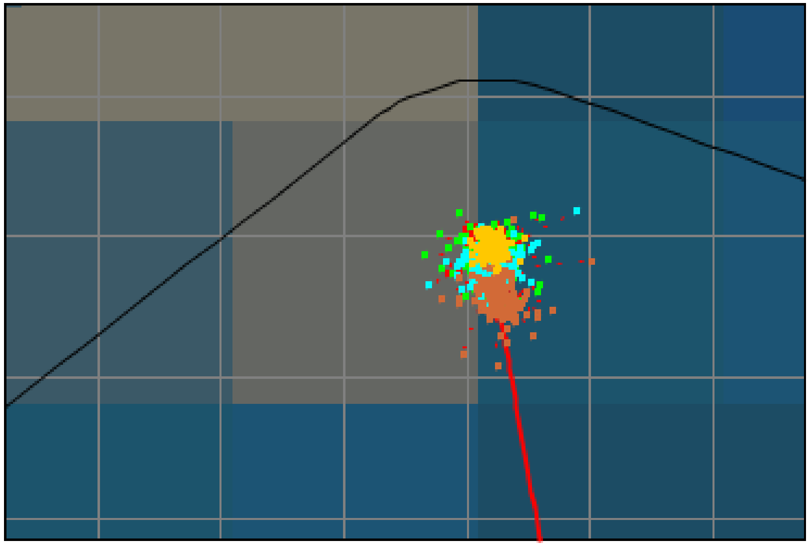
Launch Safety Analysis

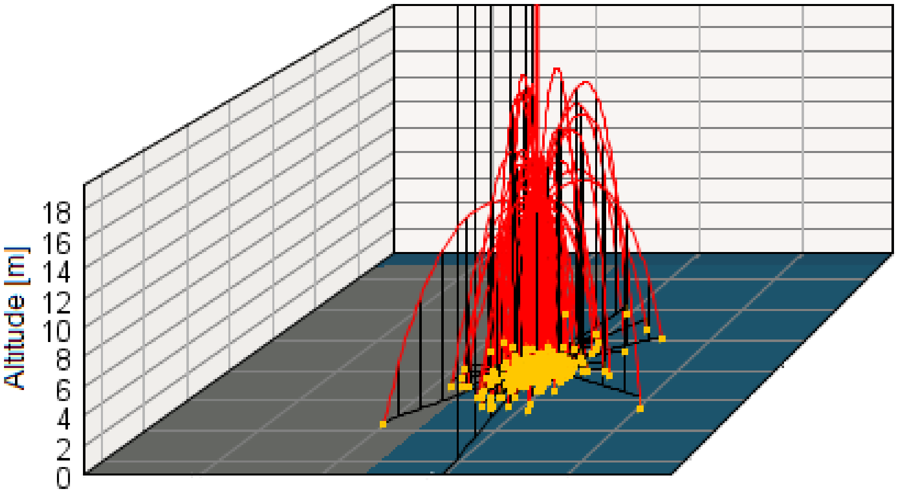
- Risk of casualty and fatality in case of failure
  - explosion performed at each time step with consequent integration of fragments till ground and computation of risk.



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; ESA can use ASTOS free-of-change.
- Contacts: service@astos-de

Leadership requires solutions

Astos Solutions

Thank you!