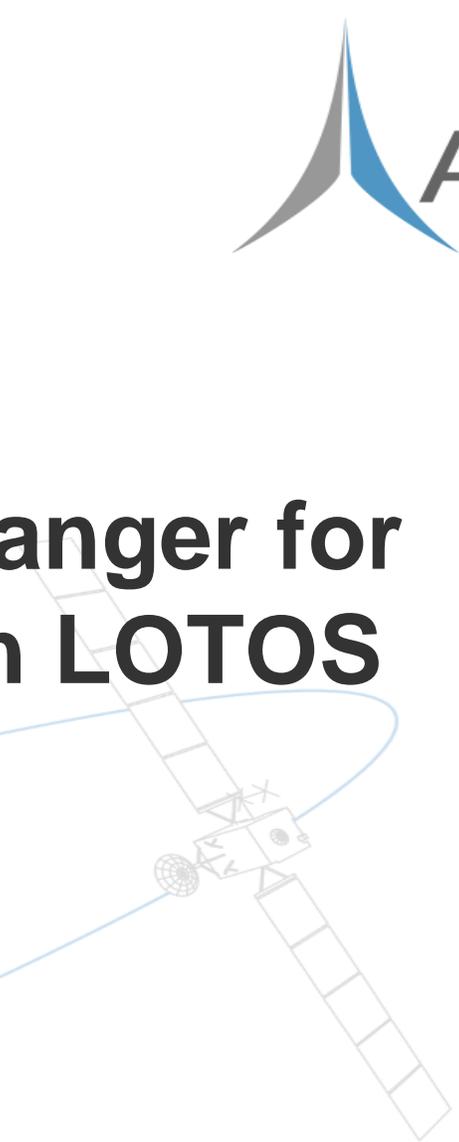


Electric propulsion as game changer for CubeSat: mission analysis with LOTOS

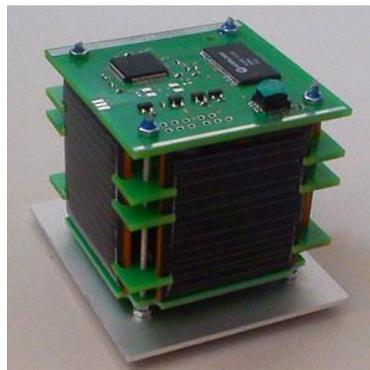
Space Tech Expo Europe
24 October 2017, Bremen (DE)

Francesco Cremaschi, Sven Schäff
Astos Solutions GmbH, Stuttgart
service@astos.de

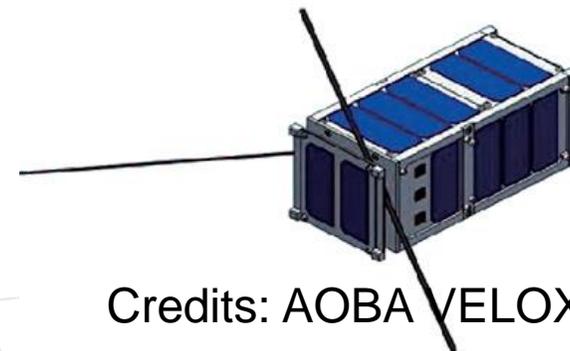


Outline

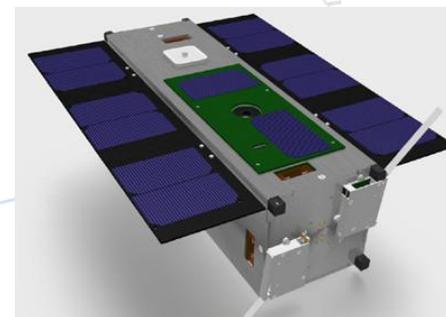
- Astos Solutions and Products
- State of art
- Motivation
- EP for orbit change
- Orbit change examples
 - Micro satellite
 - Cubesat
- Space tug example
- LOTOS
 - Introduction
 - Operational mode
- Conclusion



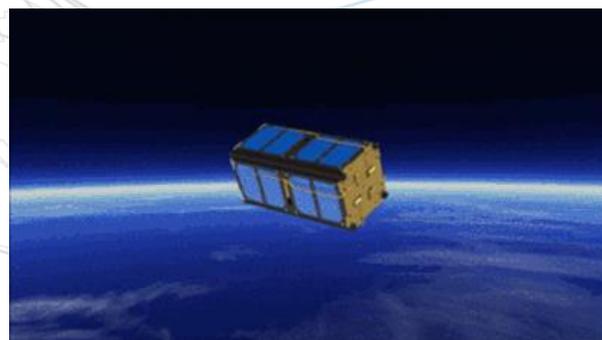
Credits: Stadoko



Credits: AOBA VELOX III



Credits: SSTL



Credits: Fachhochschule Wiener Neustadt



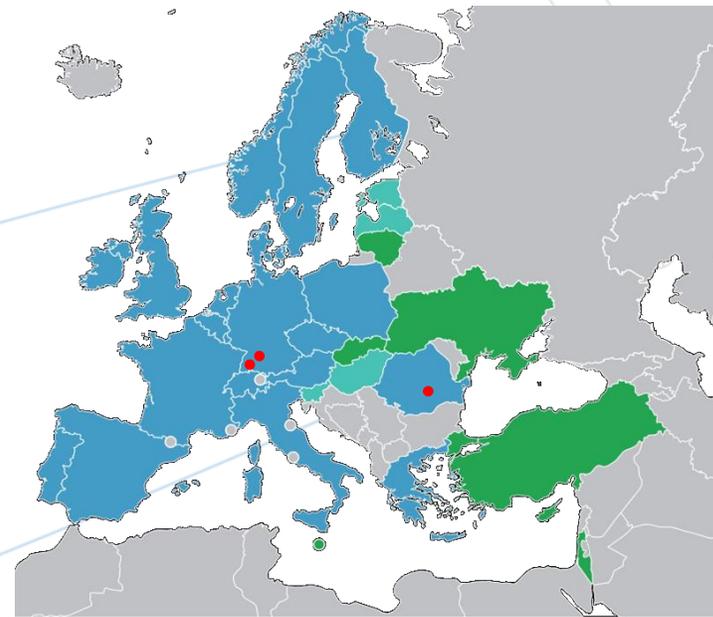
Credits: Aerospace Corporation

Astos Solutions overview

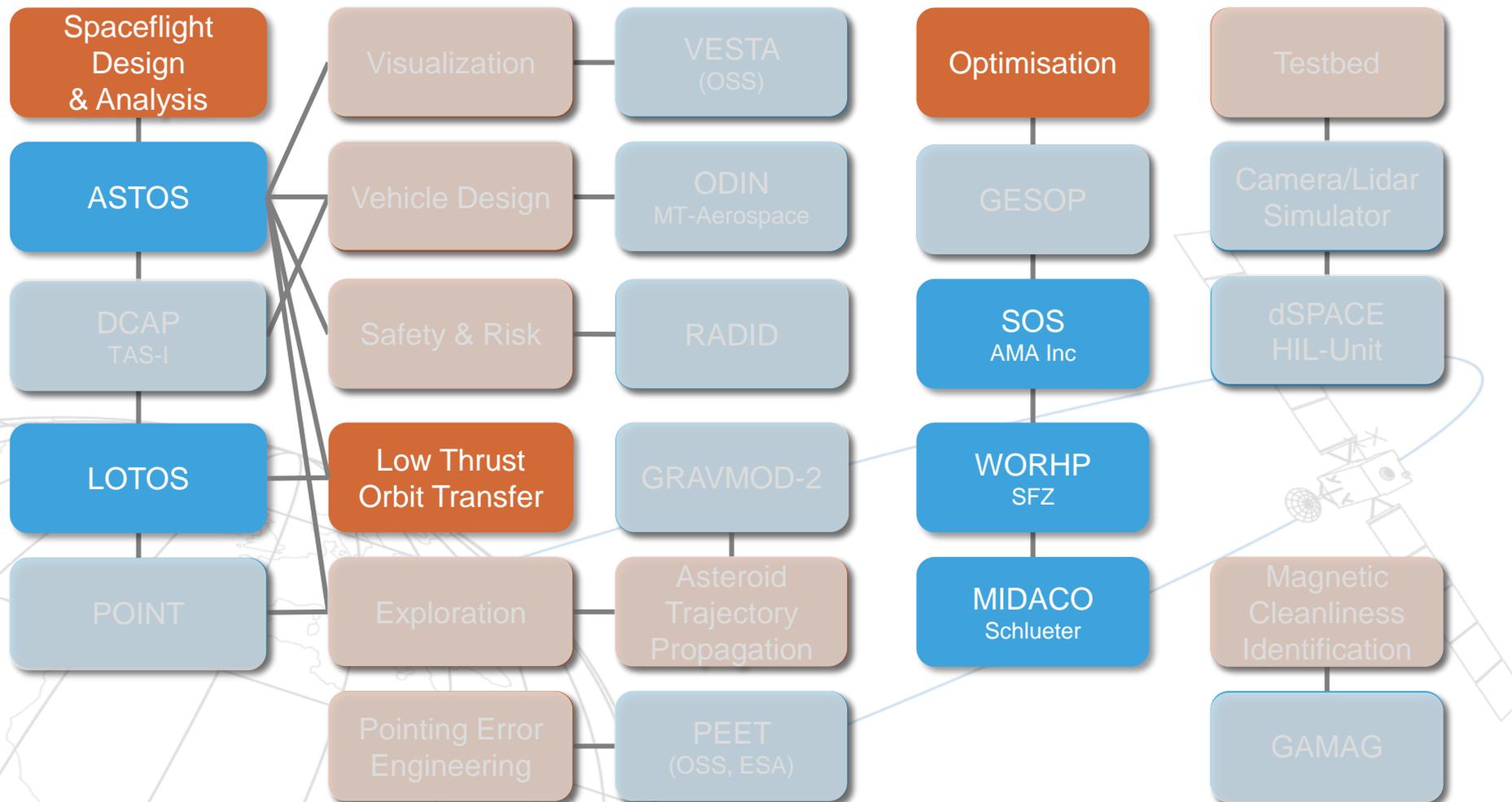
- SME with sites in Unterkirnach (DE), Stuttgart (DE), Bucharest (RO)
- Spin-Off of the Univ. of Stuttgart, standalone company since 2006
- Roots of Astos Solutions go back to 1989



Office in Stuttgart



Product overview



State of the art – Propulsion

What about Cube-sat and Micro-sat?:

- Several commercial options
 - BUSEK
 - Aerojet Rocketdyne
 - Accion Systems
 - Sitael
 - Others ...



Credits: Accion Systems

Product Image	Product Number
	PRS-101
	MR-502

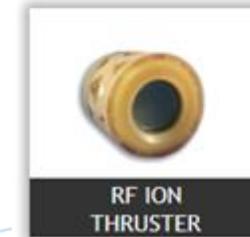
Credits: Aerojet Rocketdyne



ELECTROSPRAY THRUSTER



MICRO PULSED PLASMA THRUSTER

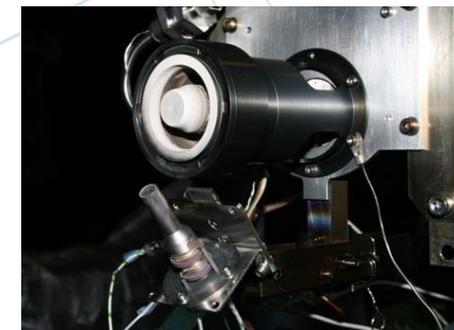


RF ION THRUSTER



HALL EFFECT THRUSTER

Credits: BUSEK



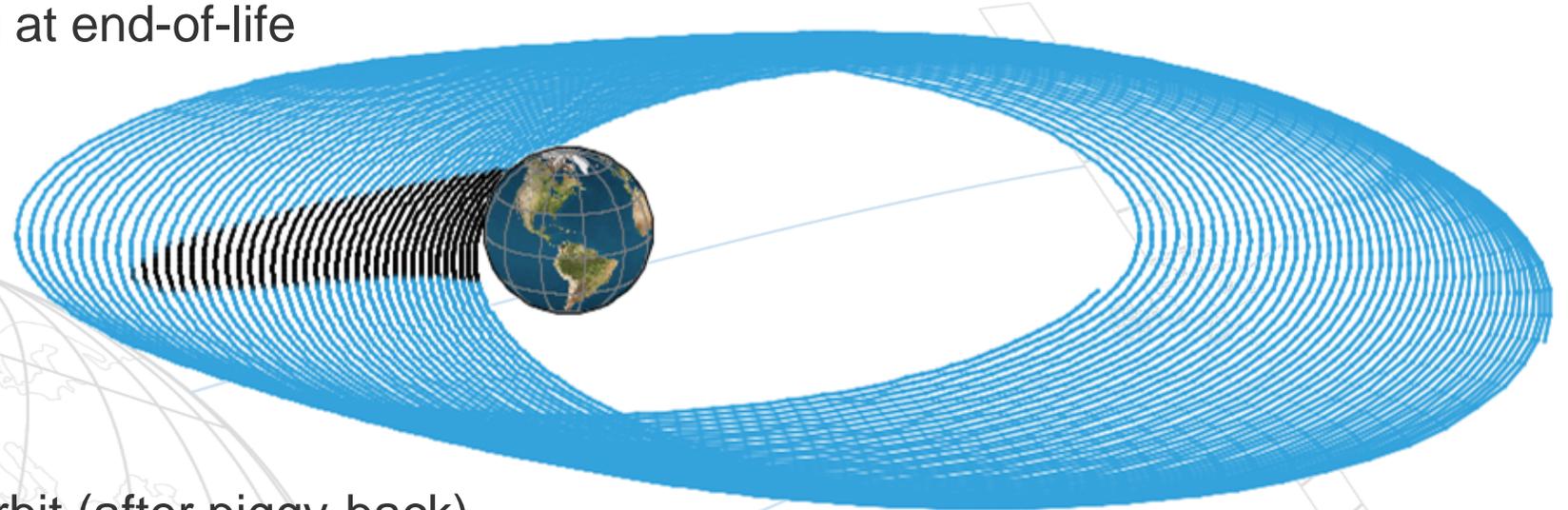
Credits: Sitael

- University studies and test (e.g. MIT, Michigan)

State of the art – Application

Low-thrust is used in space:

- Orbit change till target orbit (GTO-GEO)
- Position and Attitude control during operational phase
- De-orbit or graveyarding at end-of-life



Near future scenarios:

- Orbit change till target orbit (after piggy-back)
- Space tug for delivery and service

Credits: Astos Solutions LOTOS

Motivation

All these scenarios requires:

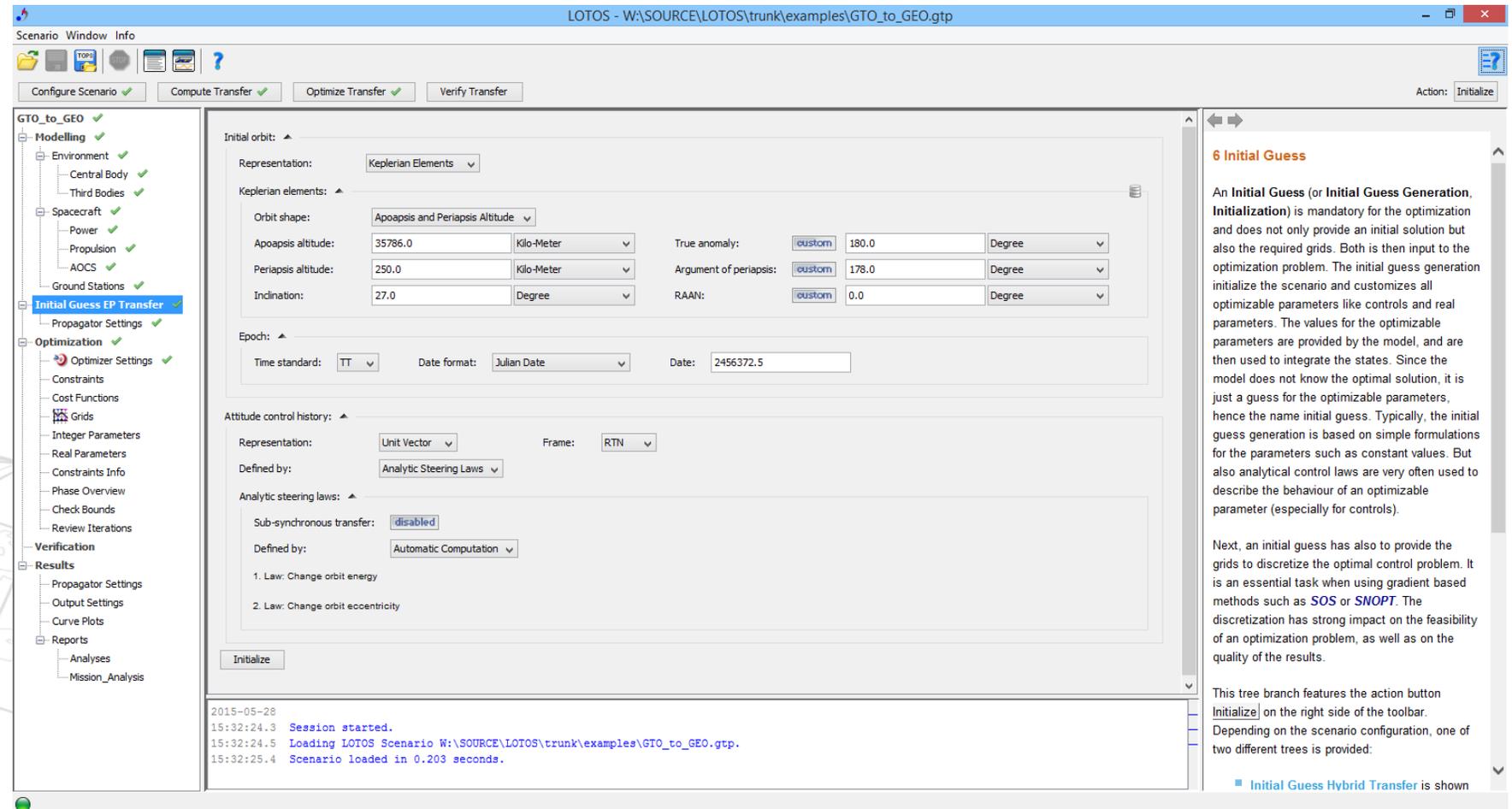
- Optimization and analysis of high-fidelity transfer trajectories
- Optimized maneuver planning
- Software for Guidance & Navigation
- Mission analysis

Is there budget/time for development of in-house tools?



COTS solution – LOTOS

- Hybrid transfers
- Electric transfer
- Controlled 6DoF attitude
- Verification of trajectories
- Database
- Post-processing
- Reports
- Windows & Linux platform



The screenshot displays the LOTOS software interface for configuring a transfer scenario. The window title is "LOTOS - W:\SOURCE\LOTOS\trunk\examples\GTO_to_GEO.gtp". The interface includes a toolbar with buttons for "Configure Scenario", "Compute Transfer", "Optimize Transfer", and "Verify Transfer". A left-hand tree view shows the scenario structure, with "Initial Guess EP Transfer" selected. The main panel is divided into sections for "Initial orbit" and "Attitude control history".

Initial orbit:

- Representation: Keplerian Elements
- Keplerian elements:
 - Orbit shape: Apoapsis and Periapsis Altitude
 - Apoapsis altitude: 35786.0 Kilo-Meter
 - Periapsis altitude: 250.0 Kilo-Meter
 - Inclination: 27.0 Degree
 - True anomaly: iocustom 180.0 Degree
 - Argument of periapsis: iocustom 178.0 Degree
 - RAAN: iocustom 0.0 Degree
- Epoch:
 - Time standard: TT
 - Date format: Julian Date
 - Date: 2456372.5

Attitude control history:

- Representation: Unit Vector
- Frame: RTN
- Defined by: Analytic Steering Laws
- Analytic steering laws:
 - Sub-synchronous transfer: disabled
 - Defined by: Automatic Computation
 - 1. Law: Change orbit energy
 - 2. Law: Change orbit eccentricity

An "Initialize" button is located at the bottom of the main panel. A status bar at the bottom shows a log of events:

```
2015-05-28
15:32:24.3 Session started.
15:32:24.5 Loading LOTOS Scenario W:\SOURCE\LOTOS\trunk\examples\GTO_to_GEO.gtp.
15:32:25.4 Scenario loaded in 0.203 seconds.
```

On the right side, a "6 Initial Guess" section provides a detailed explanation of the initial guess process, including an "Initialize" button in the toolbar.

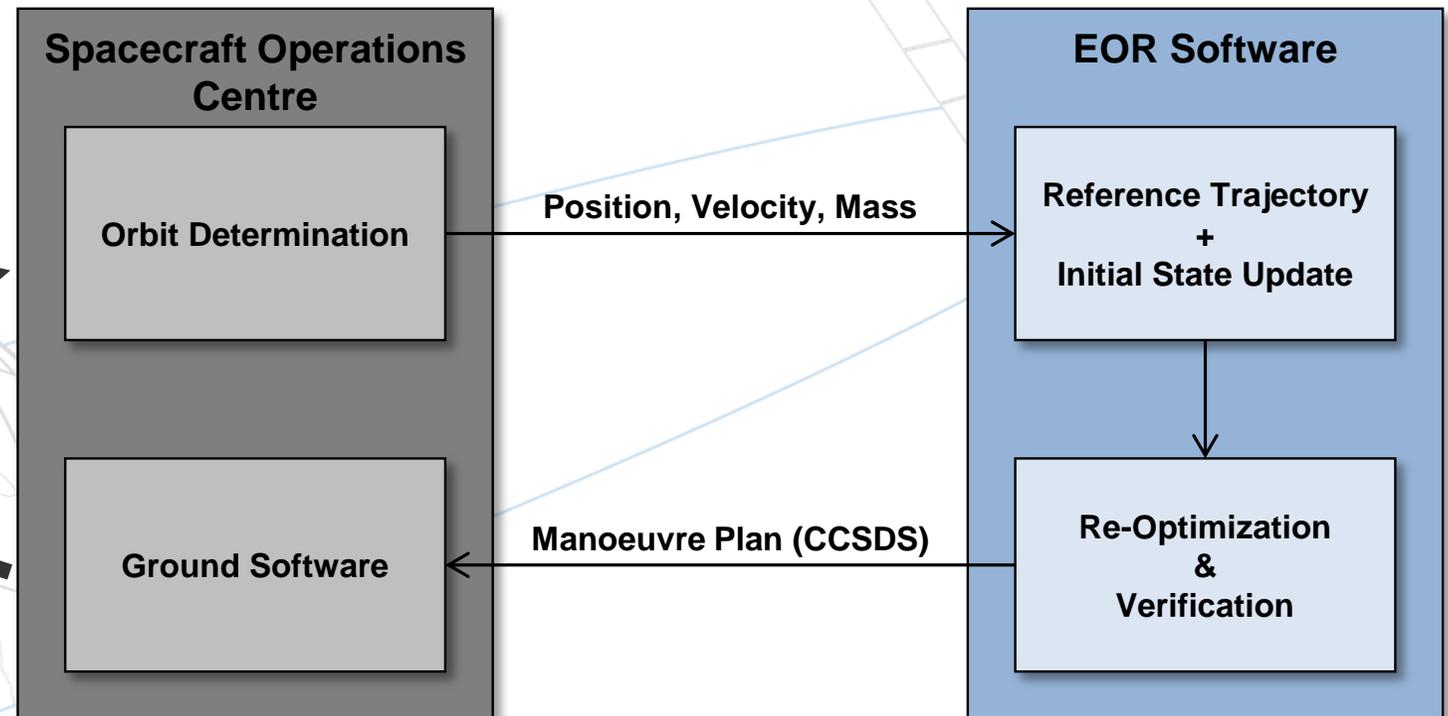
LOTOS – operational aspects

Once the trajectory (and satellite) is optimized, operational aspects have to be considered:

- Re-optimization of trajectory after separation from launcher to consider injection errors.
- Periodic re-optimization of trajectory to account for perturbations, attitude errors and underperformance of propulsion.
- New maneuver plan of next cycle is uploaded to the satellite.



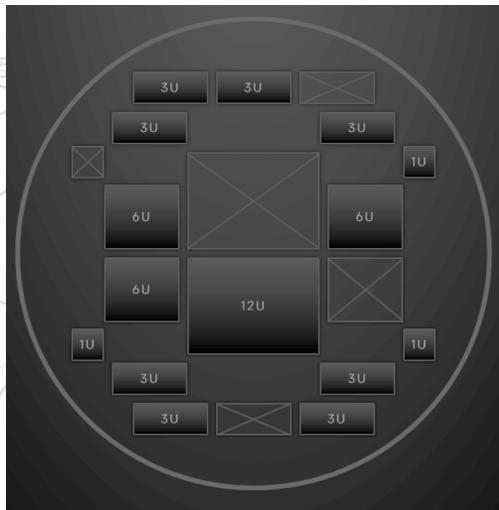
Credits: Safran



Electric Propulsion for orbit change – Example

Several satellites are launched in a single orbit:

- PSLV
- Soyuz
- Even more in the future (Falcon, Electron, etc.)



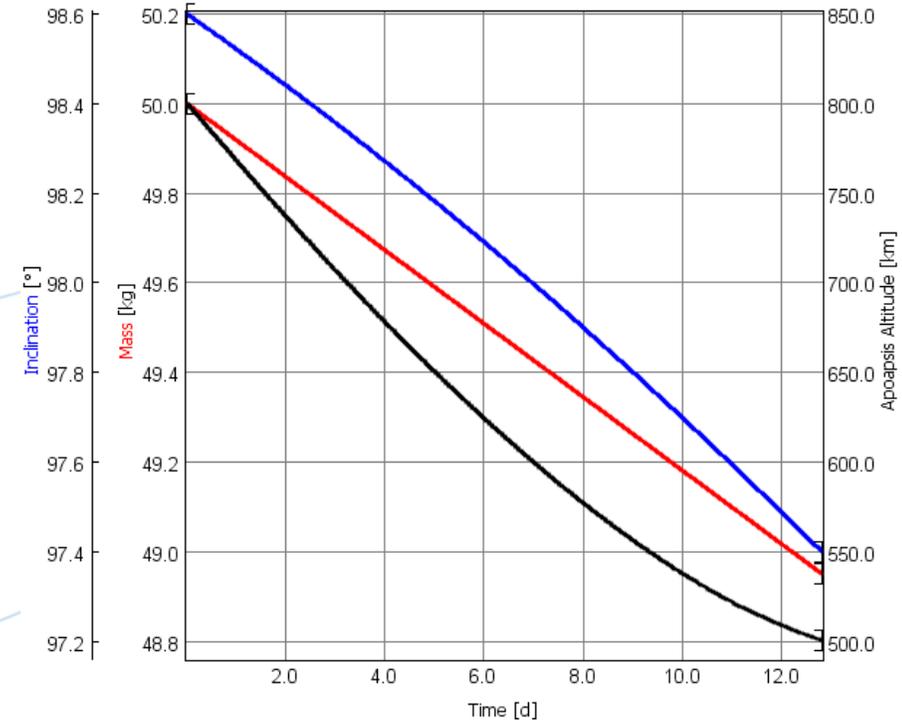
Credits: Rocket Lab



Credits: Glavkosmos

EP for orbit change – Microsat example

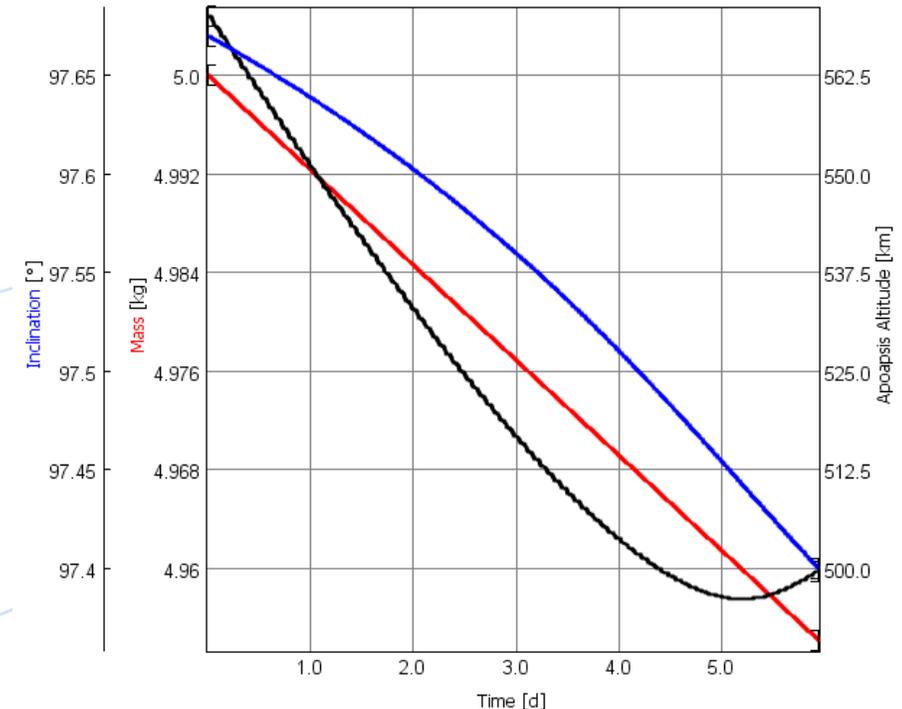
- PLSV delivery at 800 km SSO → Not compliant with end-of-life regulations.
- Target orbit 500 km SSO
 - Satellite mass 50 kg
 - Power = 200 W
 - Isp = 1400 s (Hall)
 - Thrust = 0.013 N
- **Final Sat mass = 48.9 kg**
- **Transfer duration = 12.8 days**
- **Delta V = 291 m/s**



Credits: AS LOTOS

EP for orbit change – 3U Cubesat example

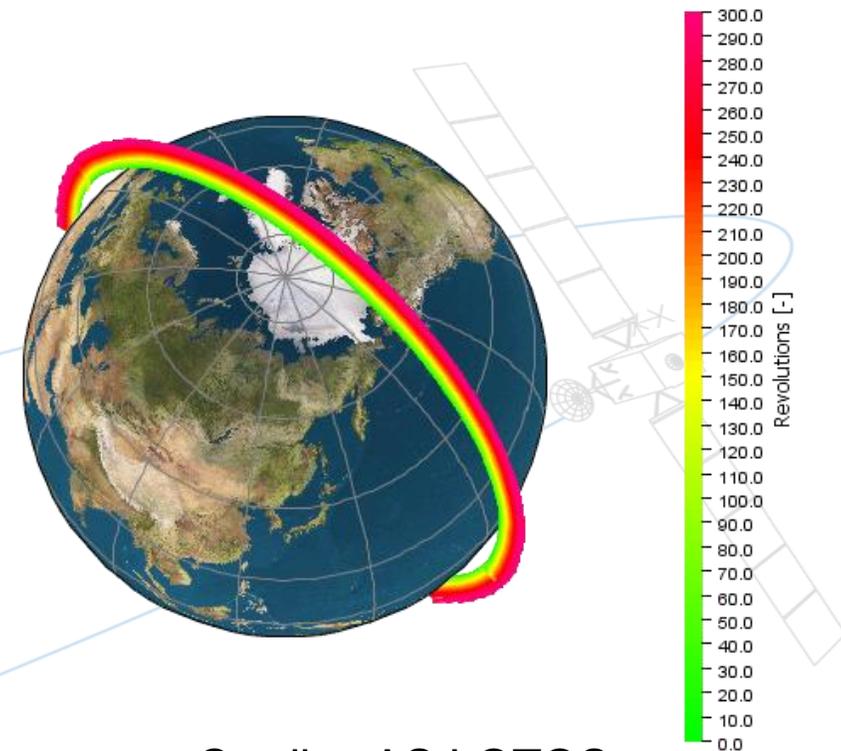
- PLSV delivery at 570 km SSO → Not compliant with end-of-life regulations.
- Target orbit 500 km SSO
 - Satellite mass 5 kg
 - Power = 15 W
 - Isp = 800 s (Electrospray)
 - Thrust = 0.7 mN
- **Final Sat mass = 4.954 kg**
- **Transfer duration = 5.9 days**
- **Delta V = 72 m/s**



Credits: AS LOTOS

Space tug – Cubesat/Microsat applications

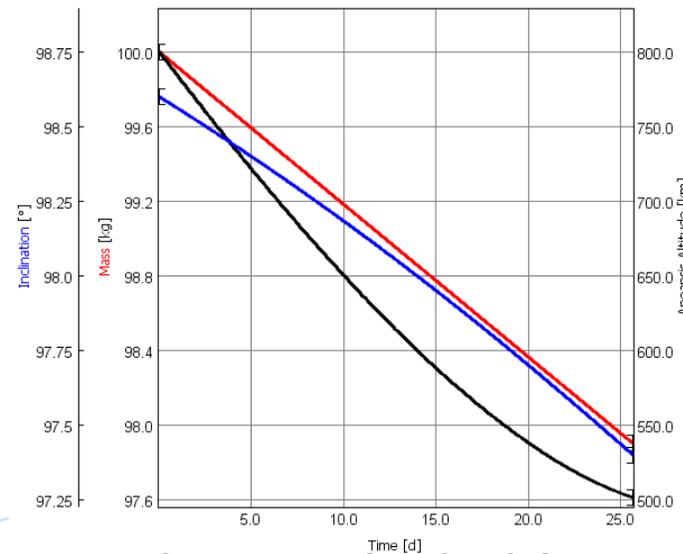
- Delivery of a satellite to its final orbit
- Constellation deployment without impacting life-time of satellites
- De-orbit of not active satellites
- *Service of satellites in LEO for repositioning, life-extension, repair and graveyarding.*



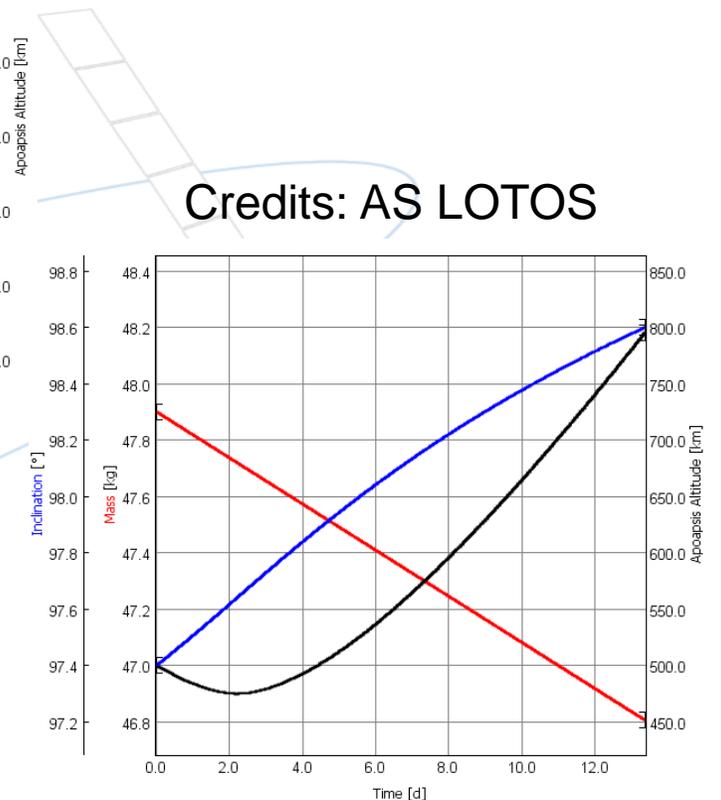
Credits: AS LOTOS

Space tug – Does it make sense?

- Microsat example from 800 km to 500 km
 - Satellite mass 50 kg
 - Tug mass = 50 kg
 - Power = 200 W
 - Isp = 1400 s (Hall)
 - Thrust = 0.013 N
- **Final Tug mass = 47.9 kg**
- **Transfer duration = 25.6 days**
- Tug return to 800 km SSO
 - **Final Tug mass = 46.8 kg**
 - **Transfer duration = 13.4 days**



Credits: AS LOTOS



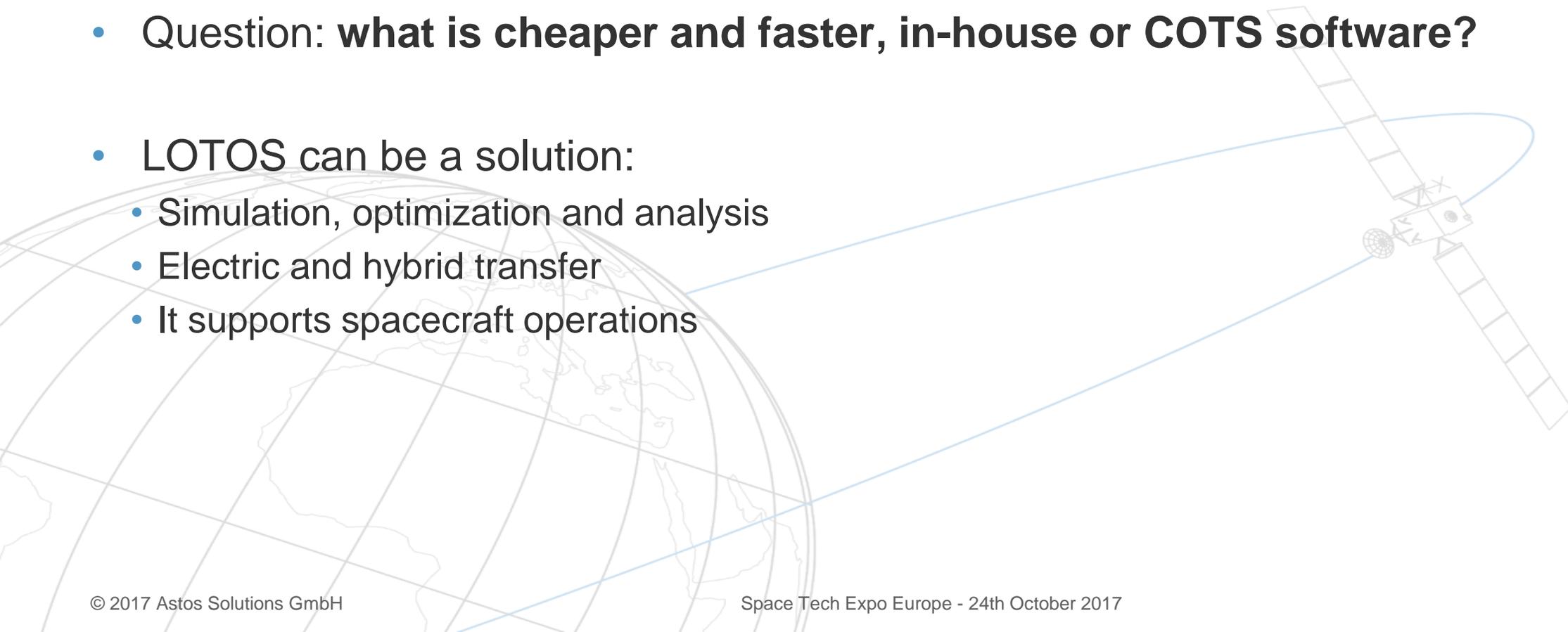
Credits: AS LOTOS

Conclusion

- Electric propulsion is a well proven technology, the miniaturisation of it allows the implementation on micro-satellites and cubesats.
- This allows constellation deployment, end-of-life grave yarding and modification of orbit parameters reached by piggy-back deployment.
- Preliminary trajectory optimizations show interesting results for micro-satellites and cubesats.
- Question: **are the advantages repaid by the propulsion sub-system cost?**
- The application of an electric propulsion Tug is questionable for micro-satellites, not interesting for cube-sat due to volume and mass limitations.

Conclusion

- The increased complexity of mission analysis and trajectory optimization requires experience and powerful tools for the design and operation of such vehicles.
- Question: **what is cheaper and faster, in-house or COTS software?**
- LOTOS can be a solution:
 - Simulation, optimization and analysis
 - Electric and hybrid transfer
 - It supports spacecraft operations



Leadership requires solutions



you!

For a live demo and more information, please visit us at stand J20.

