

Advanced Electric Orbit-Raising Optimization and Analysis with LOTOS 2

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Outline



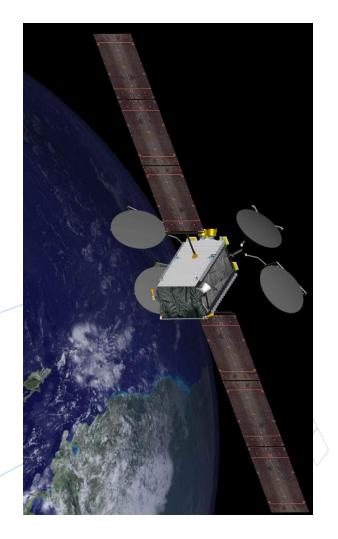
Orbit Raising

Motivation

Key Features

Software Overview

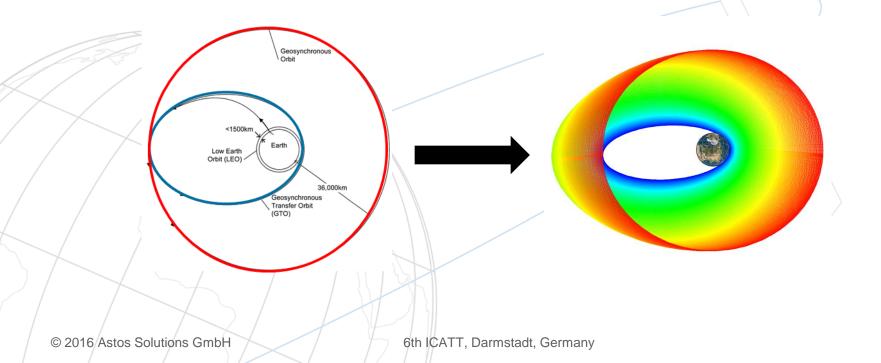
Conclusion



Electric Propulsion for Orbit Raising



- 1. Most telecom spacecraft are launched into a transfer orbit
- 2. Spacecraft employs electric propulsion to transfer from launch orbit to the mission orbit
- 3. GTO-GEO transfer
 - ~12% propellant consumption (vs. 40% chemical)
 - Transfer duration prolonged up to several months

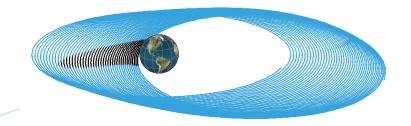


Motivation



• Optimization and analysis of high-fidelity transfer trajectories

• Optimized maneuver planning



Software for Guidance & Navigation

Mission Analysis

Key Features

• Hybrid transfers and pure electric orbit-raisings

cenario 1

O to GE

- Support of operational trajectories
- Controlled 6DoF attitude
- Verification of trajectories
- Database
- Post-processing
- Reports
- Windows & Linux platform



the initia

mulation

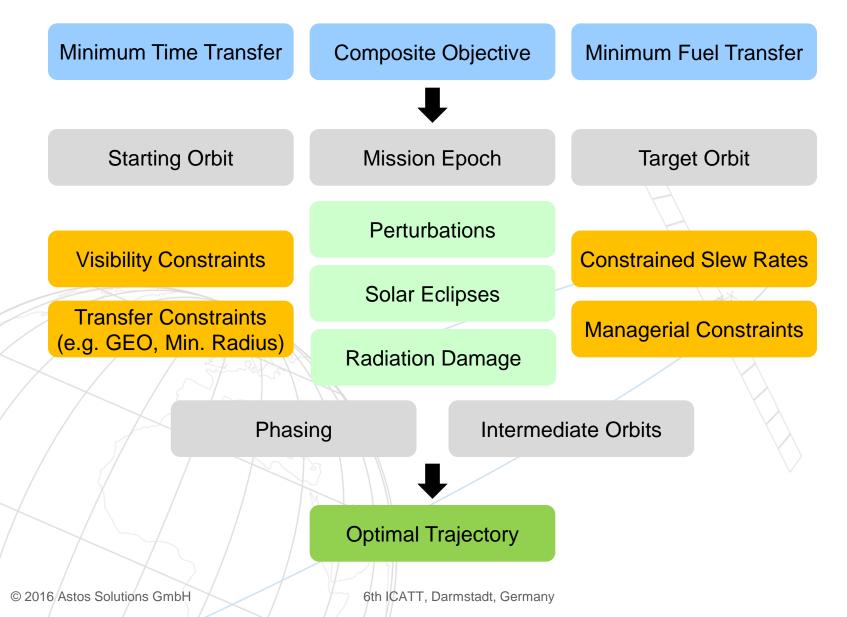




| | | | LOTOS - W:\ | SOURCE/LOTOS/trunk | example | s\GTO_to_GEO. | .gtp | | |
|---|---|-----------------------|-------------------------------|------------------------|---------|---------------|--------|-----|---|
| nario Window Info | | | | | | | | | |
| | ? | | | | | | | | |
| Configure Scenario 🖌 Compute | e Transfer 🖋 Optimize Tra | ansfer 🖋 Verify Trans | ifer | | | | | | Action: Ini |
| D_to_GEO ✓ Modelling ✓ | Initial orbit: 🔺 | | | | | | | | ^ + + |
| Environment Central Body Third Bodes Spacecraft Power Propulsion | Regresentation: Keplerian Benents v Reglerian elements: A Orbit shape: Apoppis and Periopis Abtude v | | | | | | | E v | 6 Initial Guess An Initial Guess (or Initial Guess Generativ Initialization) is mandatory for the optimizati and does not only provide an initial solution b |
| AOCS V | Periapsis altitude: | 250.0 | Kilo-Meter 🗸 | Argument of periapsis: | eustorn | 178.0 | Degree | ~ | also the required grids. Both is then input to the optimization problem. The initial guess generati |
| Ground Stations 🖋 | | | | | | | | | initialize the scenario and customizes all |
| Initial Guess EP Transfer 📝 | Inclination: | 27.0 | Degree v | RAAN: | oustom | 0.0 | Degree | ~ | optimizable parameters like controls and real |
| - Propagator Settings Optimization Optimizer Settings Constraints Constraints | Epoch: A Time standard: TT | ✓ Date format: | Julian Date 🗸 🗸 | Date: 2456372.5 | | | | | parameters. The values for the optimizable parameters are provided by the model, and are then used to integrate the states. Since the model does not know the optimal solution, it is just a quess for the optimizable parameters, |
| Ost Functions Ost Functions Sig Ords Integer Parameters Real Parameters Real Parameters Ordstands Info Phase Overview Ords Bounds Phase Overview Ords Bounds Programs Programs Output Setting Output Setting Output Analyses Massion_Analyses | Atstude control history: A Representation: Defined by: Analytic steering laws: A Sub-synchronous trans Defined by: 1. Law: Change orbit es 2. Law: Change orbit es Initialize | Automatic Computatio | | ¥) | | | | | hence the name initial guess. Typically, the init guess generation is based on simple formulation for the parameters such as constant values. Bu also analytical control hous are very often used descrobe the behaviour of an optimizable parameter (sepecially for controls). Next, an initial guess has also to provide the grids to discretize the optimal control problem. Is an essential task when using gradient based methods such as SOS or SMOPT. The discretization problem, as well as on the quality of the results. |
| | 15:32:24.3 Session sta | TOS Scenario W:\SOURC | E\LOTOS\trunk\examples\ s. | GIO_to_GEO.gtp. | | | | | Initialized on the right side of the totical. Depending on the scenario configuration, one of two different trees is provided: |

Software Scheme





Environment



| Radiation belt: 🔺 | | | | | | |
|---------------------|--------------------|--------------------------------------|---------------|-----------|----------------|----------|
| Defined by: | Hollow Sphere 💌 | | | | | |
| Hollow sphere: | * | | | | | |
| Inner radius | s: 7000.0 | Kilo-Meter 💌 | Outer radius | : 12000.0 | Kilo-Meter | T |
| Dwell time as st | tate: disabled req | quired for appropriate cost function | , | | | |
| Stationary Ring (GB | EO-Ring): 🔺 | | | | | E |
| Inner radius: | 42050.0 | Kilo-Meter | Outer radius: | 42250.0 | Kilo-Meter | T |
| Lower height: | -75.0 | Kilo-Meter 💌 | Upper height: | 75.0 | Kilo-Meter | V |
| Environment effect | ts: 🔺 | | | | | |
| Atmospheric dra | ag: disabled | | | | | |
| Solar radiation p | pressure: disabled | | | | | |
| Solar wind: | disabled | | | | | |
| Third body pert | | | | | | |
| Third body per d | | | | | | |
| Ephemeris computa | ation: SPICE 💌 | | | | | |
| | Tastell | | | | | A sta |
| Ground stations: 🔺 | | | | | | |
| Add Re | emove | | | | | |
| | Name | Altitude | Dea | Longitude | Degree | Latitude |
| - Weilheim | | 1.0 | Deg 11.1 | | Degree 47.9 | |
| Perth | | 22.2 | 115. | | -31.8 | |
| Item: 🔺 —— | | | | | | Ę- |
| Name: | Weilheim | | | | | |
| Altitude: | 1.0 | Meter | | | | |
| Longitude: | 11.1 | Degree 🔹 | | | | |
| Latitude: | 47.9 | Degree 💌 | | | | |
| | , | , | | | | |

Spacecraft

| | | Slew rates: 🔺 | | | | E | |
|--|----------------------|---------------------------------|-------------------------------|--|-------------------------|---------|---------------------|
| Spacecraft: 🔺 | | Values are used during optimiza | ation as path constraint or L | agrange cost, and for the analys | is. | | |
| Total mass: 1000.0 | Kilogram 💌 | About body x axis: 🔺 | | | | | |
| | Meter**2 | EP on Upper Limit 💌 | 150.0 | Degree/Hour | - | | |
| Reflectivity coefficient: 1.3 | C _R u | EP off Upper Limit 💌 | 200.0 | Degree/Hour | • | | |
| Drag coefficient: 2.5 | C _D u | About body y axis: 🔻 | Pro | pulsion: 🔺 | | | |
| Moments of inertia: 🔺 | | About body z axis: 🔻 | | Thrust: 🔺 | | | |
| XX: 700.0 Kilogram*Meter** | *2 💌 | Maximum torque: 0.0 | 0015 | Defined by: Cons | tant 💌 | | |
| YY: 50.0 Kilogram*Meter** | | Maximum wheel momentum: | 0 | Thrust: 0.15 | | Newton | |
| ZZ: 700.0 Kilogram*Meter** | *2 • | 1st star tracker: 🔺 🛛 🖻 | nabled | Specific impulse: 🔺 | | | |
| | $\langle \rangle$ | Only for analysis. | | Defined by: Cons | tant 💌 | | |
| ~ ~ | \sim | Boresight direction: 🔺 | | I _{SP} 2000 | .0 | Second |] |
| plume | | x: 1.0 | у: | PPU efficiency: | 100.0 | Percent | T |
| | \sim | Field of view: 5.0 | 0 | Minimum permissible power: | 0.0 | Watt | • |
| | ★z | 2nd star tracker: 💌 🛛 er | nabled | Maximum permissible power: | 1000.0 | Watt | • |
| | Γ T | | | Bang-Bang thrust control: | disabled | | |
| | | | | Schedule: | disabled | | |
| | ×× | | | Edipse shutdown: Minimum sun angle: | 10.0 | Degree | ▼ only for analysis |
| | | | | Firing limitations: | enabled | , | |
| Solar array: | 1 7 API as | | | Only for analysis. | | | |
| Reference area: 37.5 | Meter**2 | | | Minimum firing duration: | | 10.0 | Minute |
| Power output: 3000.0 | Watt | | | Maximum firing duration: | | 2.0 | Year |
| | | | | Minimum period between two | firings (cold start): | 30.0 | Minute |
| Battery: enabled | | Ę: | | Minimum period between two | o firings (warm start): | 10.0 | Minute |
| Capacity: 6000.0 Depth of discharge: 70.0 | Watt*Hour Percent | | | Thrust vector disturbance: | disabled | | |
| | Ji crean | | | | | | |

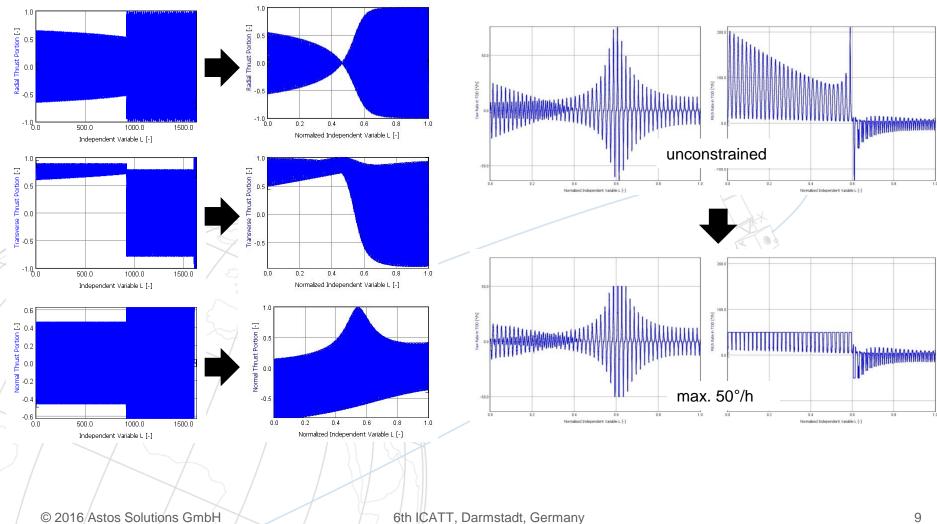
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K | Ast

S

Dynamics



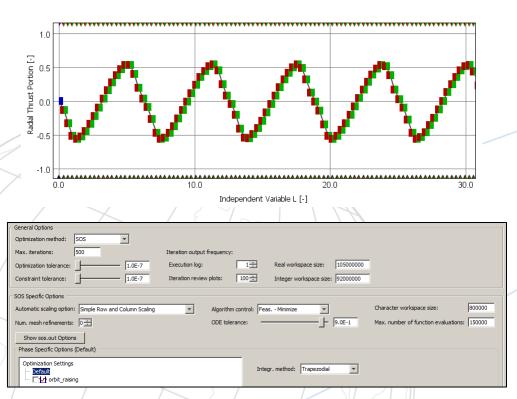


Optimization



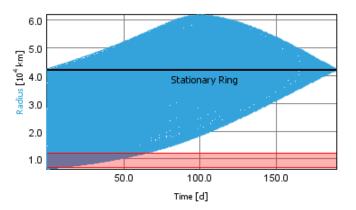
Solvers

- MIDACO (ant colony optimization)
- SOS (Sparse Optimization Software)
- WORHP (European sparse NLP solver)



| inal I | nal Boundary Constraints | | | | | | | |
|----------------|-------------------------------------|--|--|--|--|--|--|--|
| Item Selection | | | | | | | | |
| | Name | | | | | | | |
| 5 | eccentricity_(range) | | | | | | | |
| 6 | inclination_(range) | | | | | | | |
| 7 | apoapsis | | | | | | | |
| 8 | periapsis | | | | | | | |
| 9 | circular_radius | | | | | | | |
| 10 | circular_velocity | | | | | | | |
| 11 | radial_velocity | | | | | | | |
| 12 | periapsis_van_Allen_(lower_limit) | | | | | | | |
| 13 | geographic_longitude_(range) | | | | | | | |
| 14 | max_transfer_duration_(upper_limit) | | | | | | | |
| 15 | equinoctial_p | | | | | | | |
| 16 | equinoctial_f | | | | | | | |
| 17 | equinoctial_g | | | | | | | |
| 18 | equinoctial_h | | | | | | | |
| 19 | equinoctial_k | | | | | | | |
| 20 | equinoctial_L | | | | | | | |





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User Interface

Astos

Frontend and command line interface

Customizable output

- Scenario input and output (scalars, functions, ...)
- Maneuver plan and eclipses as dedicated output files

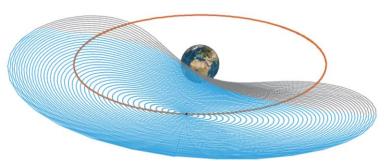
Automatic post-processing

Customizable (e.g. AOCS, EP, eclipses, ...)

Reports

- Customizable
- Automatic (1-click)

| Description: | | | | |
|-------------------|--|----------|--------|--|
| Content template: | A | | | |
| GEN ₩+ | ^{2.56} | | | |
| Body Text | Default | • A* 🖲 B | | |
| Missior | n Analysis Rej | port | | |
| 1. Overvie | ew | | | |
| 1.1 Purpose | of the Document | | | |
| Describe the | purpose of the documen | t | | |
| 1.2 Mission | Description | | | |
| | io Description e scenario description | | | |
| 1.2.2 Ground | l Stations Network | | | |
| 1.3 Initial a | nd Target Orbit | | | |
| | | Initial | Target | |
| 1 | | í | i i | |





Mission Analysis Report

1. Overview

1.1 Purpose of the Document

Describe the purpose of the document

1.2 Mission Description

1.2.1 Scenario Description

Insert here the scenario descriptio

Name Altitude (m) Longitude (°) Latitude (°) 1 Weilheim 1.0 11.1 47.9

2 Perth 22.2 115.9 -31.8

1.3 Initial and Target Orbit

| | Initial | Target |
|------------------------------|-------------|------------|
| Apoapsis altitude (km) | 35,786.000 | 35,786.000 |
| Periapsis altitude (km) | 250.000 | 35,786.000 |
| Apoapsis radius (km) | 42,164.137 | 42,164.137 |
| Periapsis radius (km) | 6,628.137 | 42,164.137 |
| Semi-major axis (km) | 24,396.137 | 42,164.137 |
| Eccentricity (-) | 0.72831 | 0.000e00 |
| Inclination (°) | 27.000 | 0.000e00 |
| Longitude ascending node (°) | 0.0 | 0.000 |
| Argument of periapsis (°) | 178.0 | 0.0 |
| True anomaly (°) | 180.0 | 0.0 |
| Julian date (d) | 2,456,372.5 | - |

Initial Guess Settings

| Independent variable | Equinoctial L |
|---------------------------------|---------------|
| Normalized independent variable | False |
| Revolutions | 259 |
| Attitude control representation | Unit Vector |
| Attitude control frame | RTN Frame |
| Attitude control from file | Calaa |

Hybrid Transfer

Astos

Chemical orbit-raising

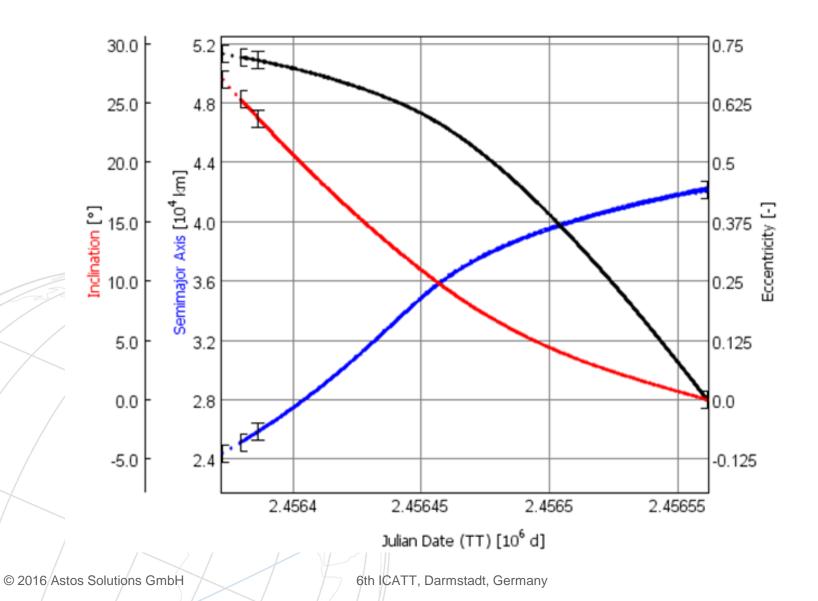
| Chemical orbit-raising: 🔺 | | | |
|-------------------------------|---------------------|---------|----------|
| 1st burn: | Periapsis 💌 | | |
| 2nd burn: | enabled Apoapsis 💌 | | |
| 3rd burn: | enabled Periapsis 💌 | | |
| Out-of-plane maneuver: | enabled | | |
| Max. duration of each burn: | 20.0 | Minute | v |
| Thrust: | 400.0 | Newton | • |
| Specific impulse: | 300.0 | Second | v |
| Max. total transfer duration: | enabled 190.0 | Day | • |
| Min. periapsis radius: | enabled 10000.0 | Kilo-Me | ter 💌 |

followed by electric orbit-raising to target orbit

| Final orbit: 🔺 | | 10.141 | | | | | | |
|-------------------------|------------------------------|---------------------|--------|------------------------|--------|------|--------|----------|
| Representation: | Keplerian Elements 💌 | Relative longitude: | custom | 37.0 | Degr | ee 💌 | | |
| Keplerian elements: 🔺 - | | | | | | | | |
| Orbit shape: | Semimajor Axis and Eccentric | ity 💌 | | | | | | |
| Semimajor axis: | 42164.137 | Kilo-Meter | T | True anomaly: | custom | 0.0 | Degree | – |
| Eccentricity: | 0.0 | None | Ŧ | Argument of periapsis: | custom | 0.0 | Degree | • |
| Indination: | 0.0 | Degree | Ŧ | RAAN: | custom | 0.0 | Degree | • |
| | | | | | | | | |

Operations

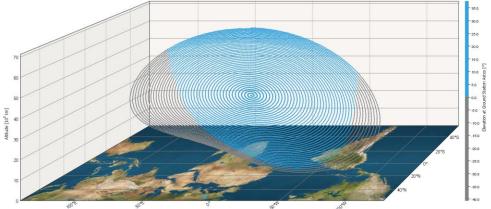




Conclusion



- Advanced tool for EOR
- Optimization & Analysis
- Hybrid Transfers



Support of Spacecraft Operations

Product website: https://www.astos.de/products/lotos Product flyer: https://www.astos.de/downloads Contact: service@astos.de

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