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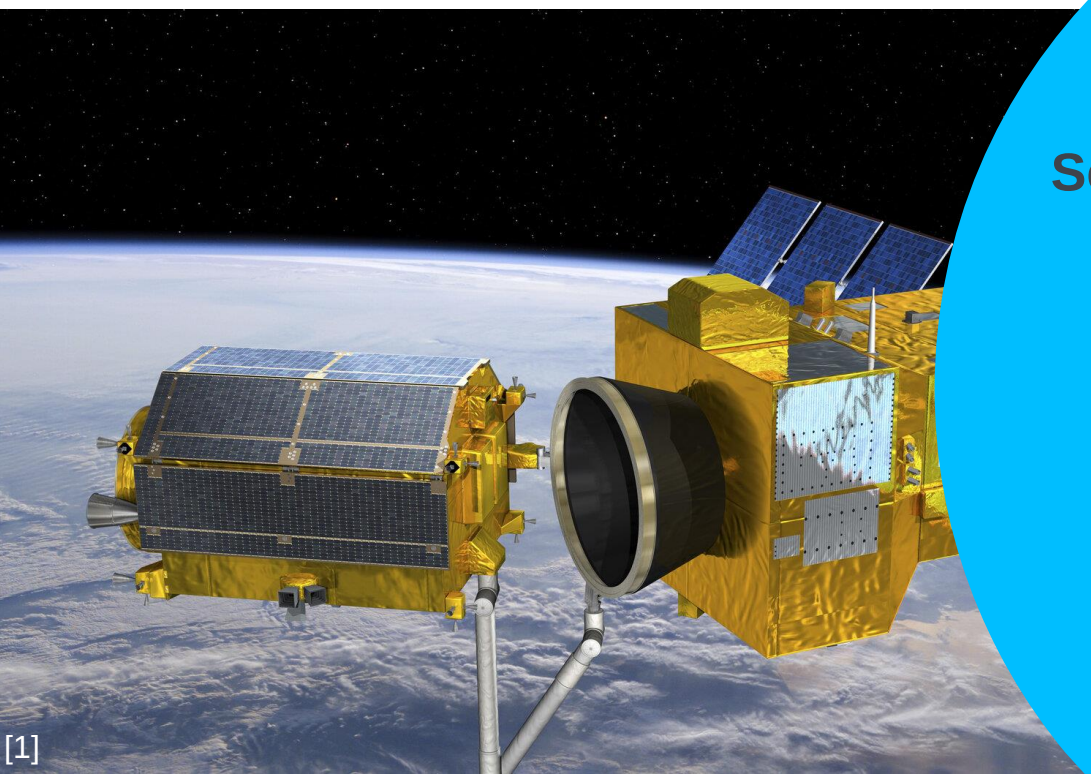


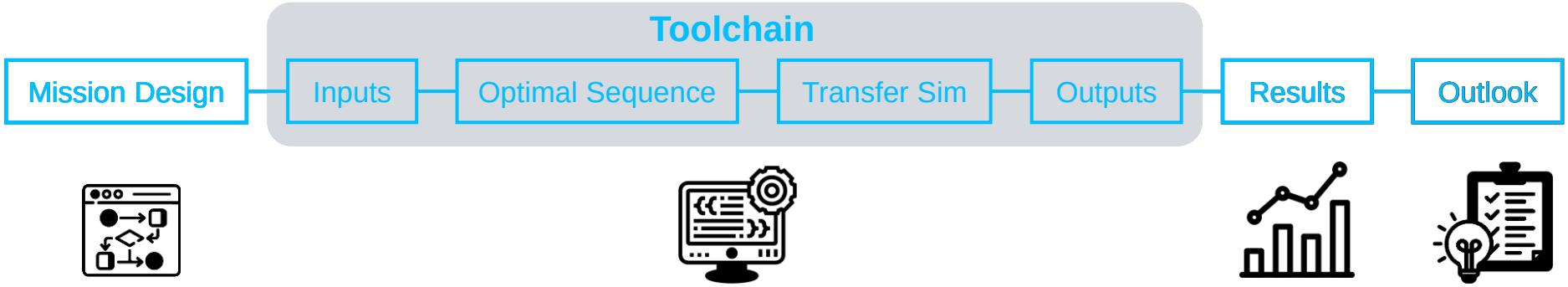
[1]

Optimizing Multiclient In-Orbit Servicing: A Mission Analysis for Geosynchronous Satellite Refueling

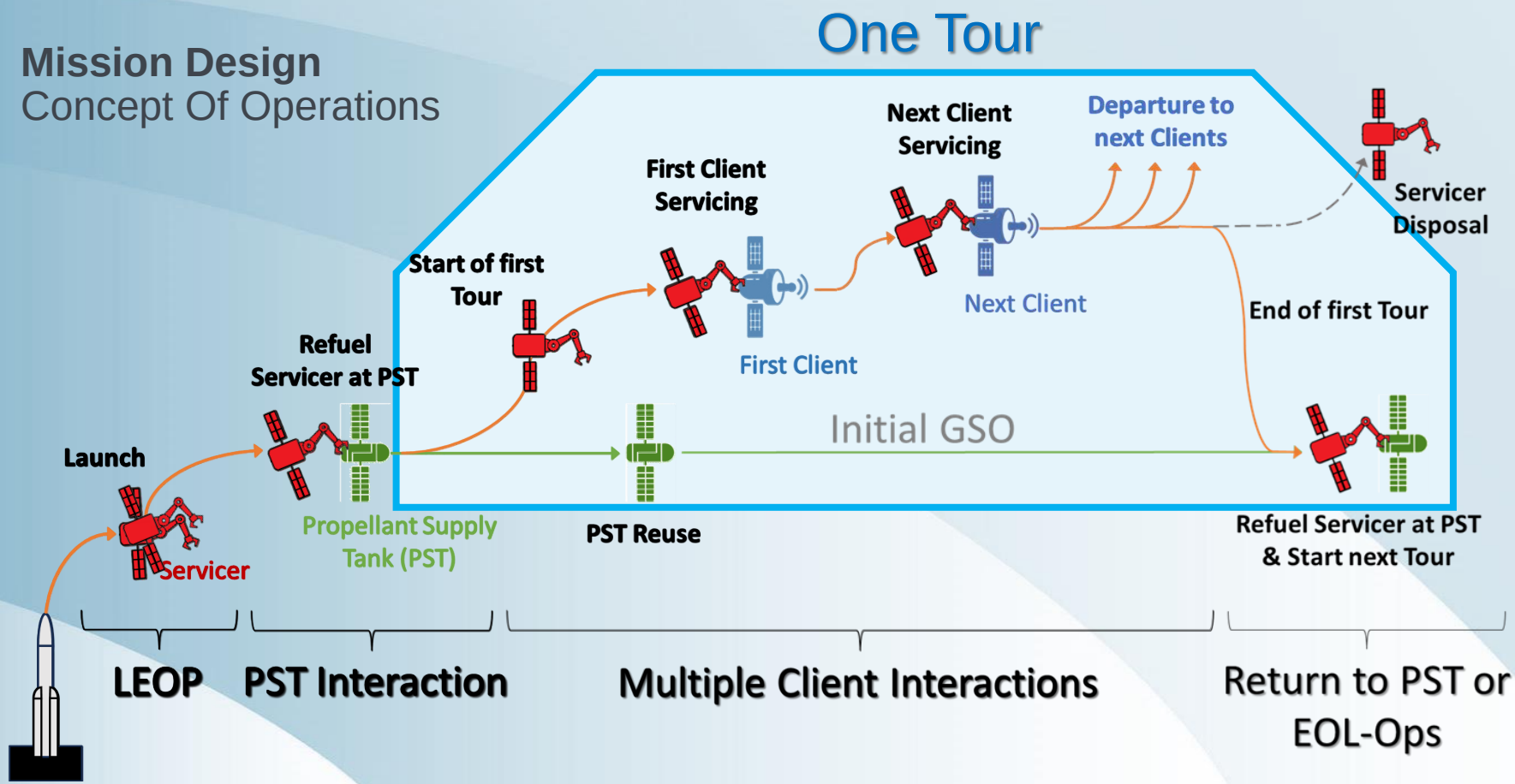
Clean Space Days 2024

Bachelor Thesis of Philipp Grüning
at IRS Stuttgart in cooperation with ESA

Agenda


Toolchain
Mission Design
Inputs
Optimal Sequence
Transfer Sim
Outputs
Results
Outlook

Mission Design
Concept Of Operations



Methodology: Toolchain
Inputs

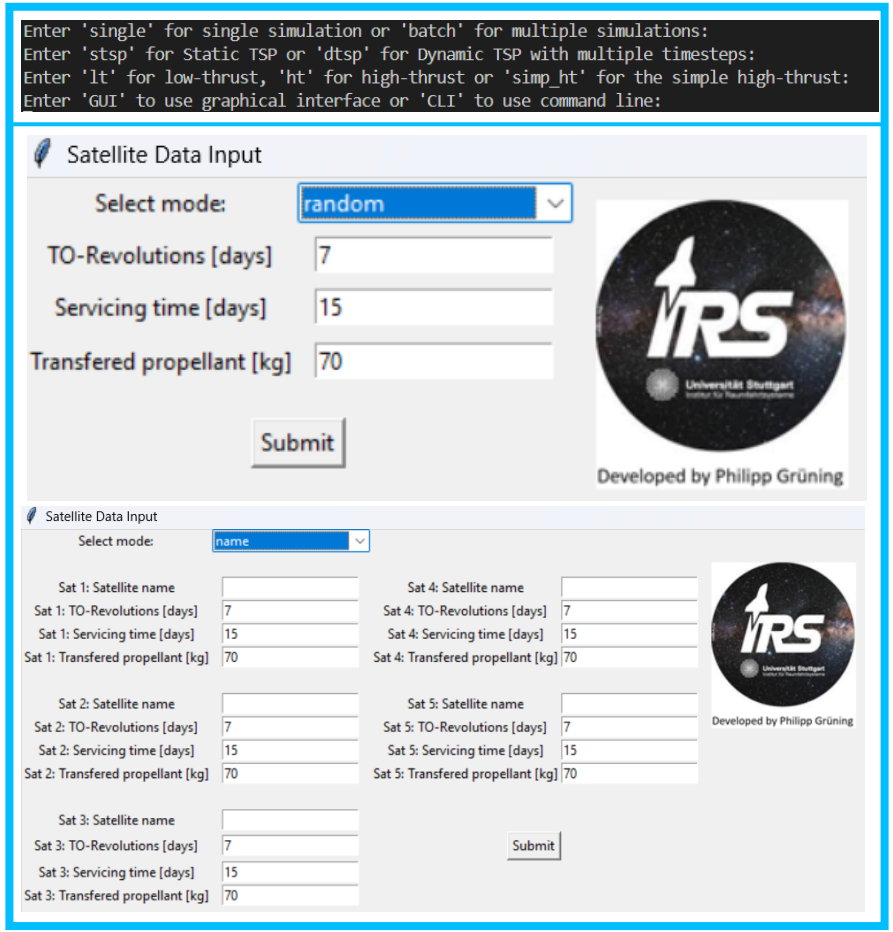
Input-Data
(client positions, config parameters)

Solving of optimal client sequence

Why? How?

Simulation of entire transfer sequence

Output-Data
(Δv, fuel & time requirements)



Toolchain
Optimal Sequence

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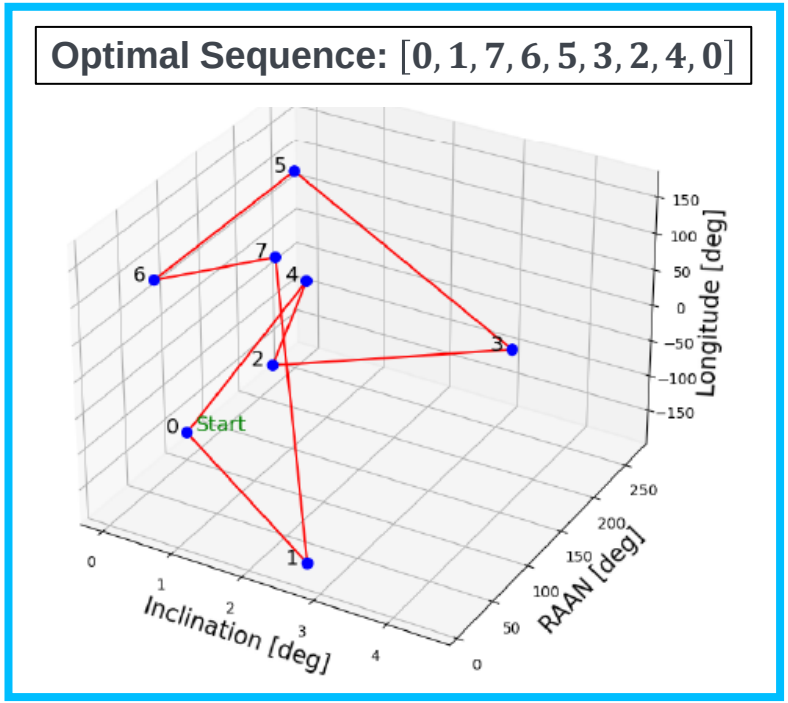


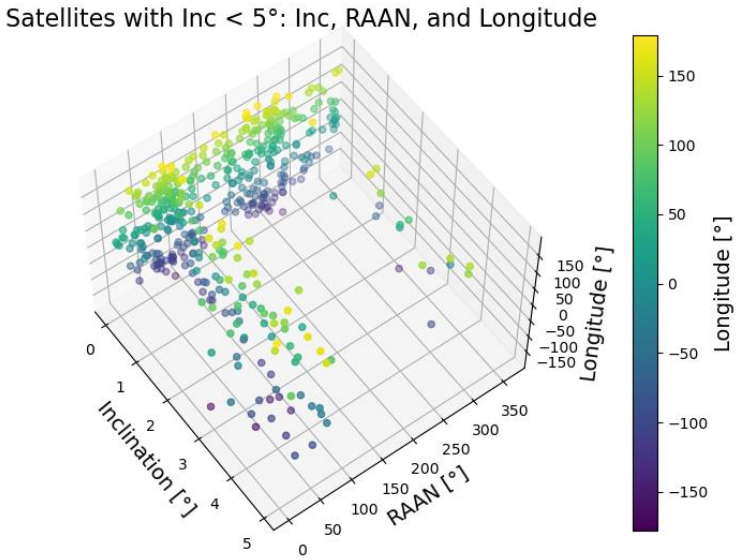
Optimal Sequence
Why do we need an algorithm?

Solving of optimal client sequence

Why? | How?

Determining the optimal sequence is **not trivial**:

- Doesn't follow a simple logic like …
  - … following a straight line in projection plot of all GSO satellites
  - … always going around the GEO belt sequentially
- Changing different orbital elements takes different amounts of Δv

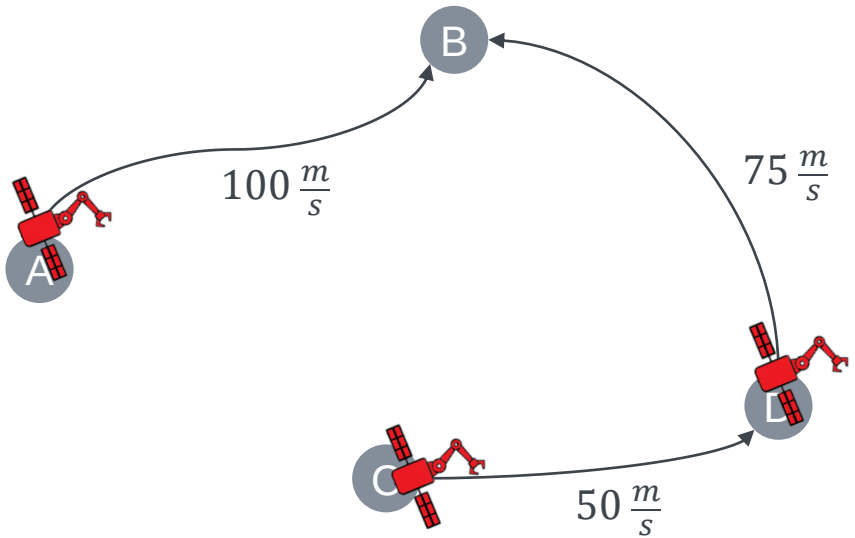


Optimal Sequence
Distance Matrix

Solving of optimal client sequence

Why? How?

	A	B	C	D
A	$0\,\frac{m}{s}$	$100\,\frac{m}{s}$	$68\,\frac{m}{s}$	$140\,\frac{m}{s}$
B	$100\,\frac{m}{s}$	$0\,\frac{m}{s}$	$104\,\frac{m}{s}$	$75\,\frac{m}{s}$
C	$68\,\frac{m}{s}$	$104\,\frac{m}{s}$	$0\,\frac{m}{s}$	$50\,\frac{m}{s}$
D	$140\,\frac{m}{s}$	$75\,\frac{m}{s}$	$50\,\frac{m}{s}$	$0\,\frac{m}{s}$



Toolchain
Transfer Simulation

Input-Data
(client positions, config parameters)

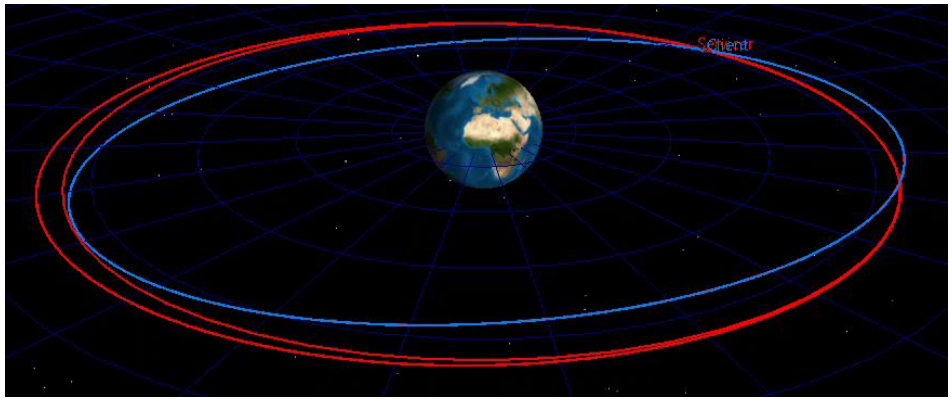
Solving of optimal client sequence

Why? How?

Simulation of entire transfer sequence

Output-Data
(Δv, fuel & time requirements)

High-Thrust Transfers



Toolchain
Transfer Simulation

Input-Data
(client positions, config parameters)

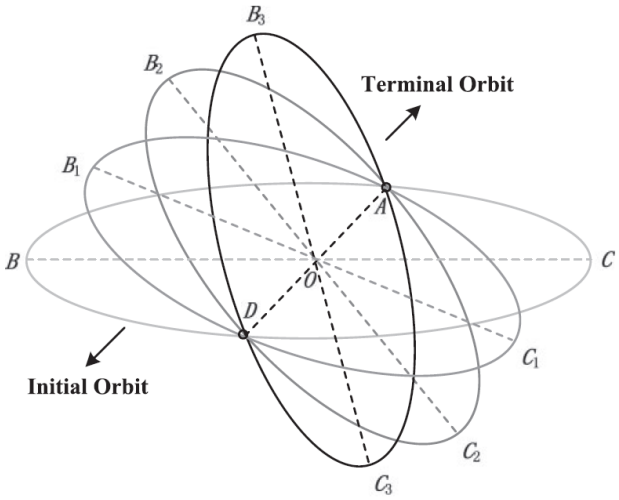
Solving of optimal client sequence

Why? How?

Simulation of entire transfer sequence

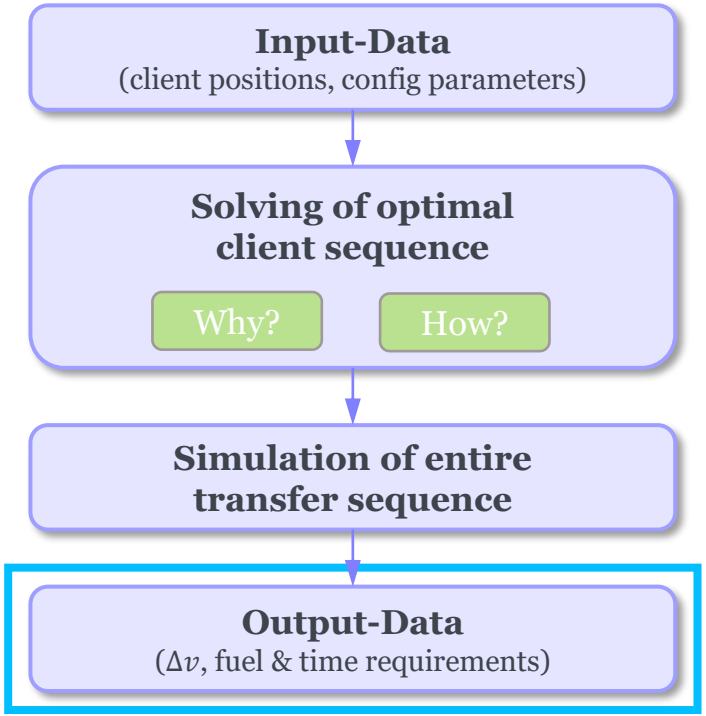
Output-Data
(Δv, fuel & time requirements)

Low-Thrust Transfers



[2]

Toolchain
Outputs

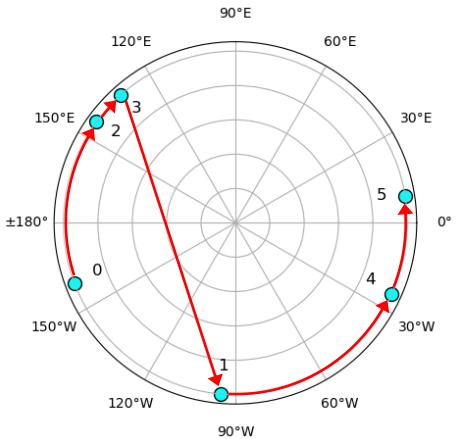



```
Transfer 1  --- Time: 25.021   | Fuel: 7.029    | deltaV: 46.011
Transfer 2  --- Time: 22.398   | Fuel: 4.22     | deltaV: 27.676
Transfer 3  --- Time: 22.317   | Fuel: 12.951   | deltaV: 85.174
Transfer 4  --- Time: 23.141   | Fuel: 9.323    | deltaV: 61.545
Transfer 5  --- Time: 69.28    | Fuel: 44.251   | deltaV: 294.775
Transfer 6  --- Time: 28.266   | Fuel: 34.318   | deltaV: 231.7
Transfer 7  --- Time: 56.807   | Fuel: 20.147   | deltaV: 137.31
Transfer 8  --- Time: 18.093   | Fuel: 20.613   | deltaV: 141.487
------------------- Results -------------------------------------
Total deltaV [m/s]: 1025.678
Total elapsed time [days]: 265.323
Total used servicer-fuel [kg]: 152.854
Total transferred fuel [kg]: 490.000
```

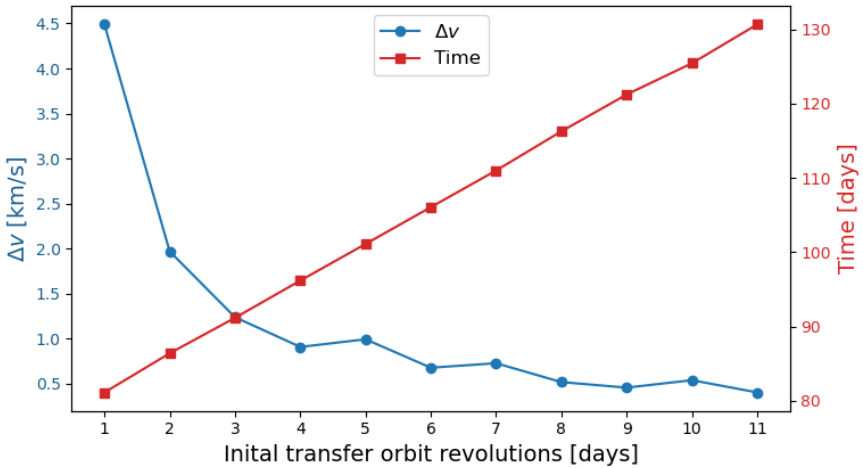
Results

Optimal sequence

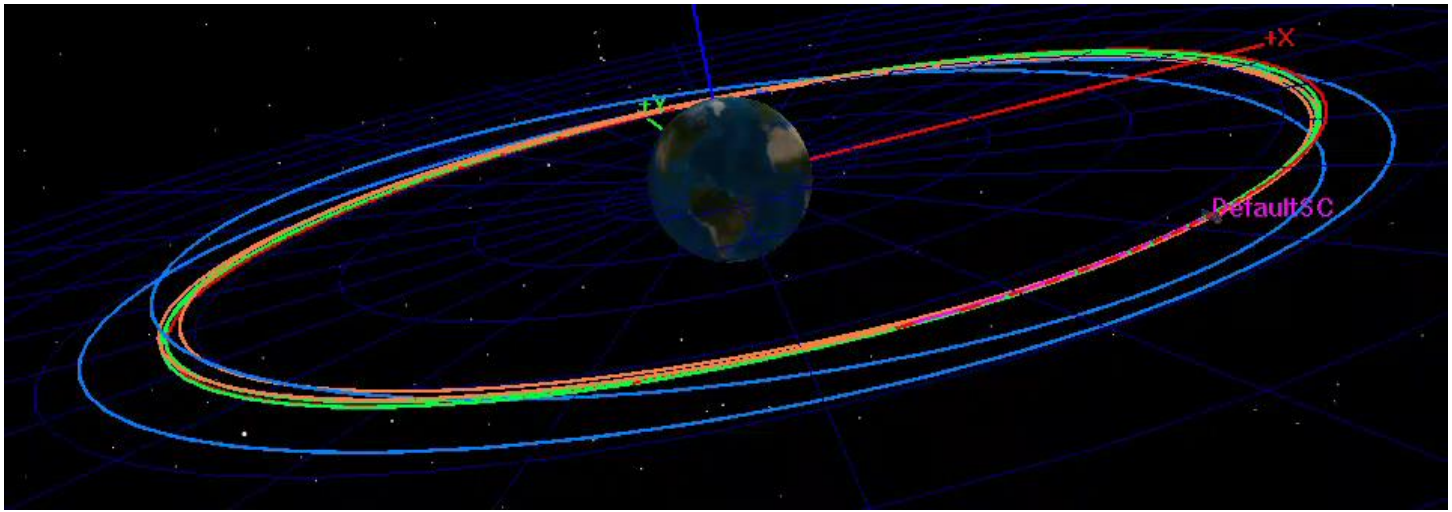
Mostly sequential around GSO belt, but increasingly deviates with growing client inclinations



Number of Transfer-Orbit-Revolutions



Full Transfer Sequence



Servicing mission with five clients

Conclusion and Outlook

Toolchain optimizes multiclient-IOS missions
with a relatively high degree of accuracy and minimal computational cost.

Key aspects of future research

- Extending the toolchain to cover orbital regions beyond geosynchronous orbits
- Overall accuracy of the underlying concepts remains an area for continual improvement

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Thank you!

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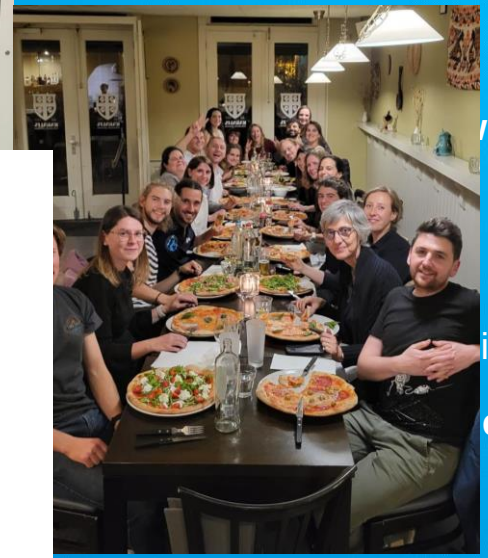

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port: **Francesco Fontanot**
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Geosynchronous Satellites:
A Case Study on Refueling Operations

Multiclient-In-Orbit-Servicing für
geosynchrone Satelliten:
Eine Studie zu Betankungsoperationen

Bachelor Thesis of
Philipp Grüning

IRS-Number: IRS-24-S-049

Professor:
Prof. Dr.-Ing. Stefanos Fasoulas

Supervisors:
Institute of Space Systems: Tharshan Maheswaran, M.Sc
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Institute of Space Systems
University of Stuttgart

September 2024

Image sources

[1] European Space Agency ESA: ESA’s e.Deorbit debris removal mission reborn as servicing vehicle. Url: https://www.esa.int/Space_Safety/ESA_s_e.Deorbit_debris_removal_mission_reborn_as_servicing_vehicle (visited on 20.08.2024)

[2] Cao, Jing; Li, Hengnian; Shen, Hongxin: “Orbital plane change maneuver strategy using electric propulsion”. In: Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering 233.7 (2019), pp. 2360–2367. Issn: 0954-4100. Doi: 10.1177/0954410018779315.