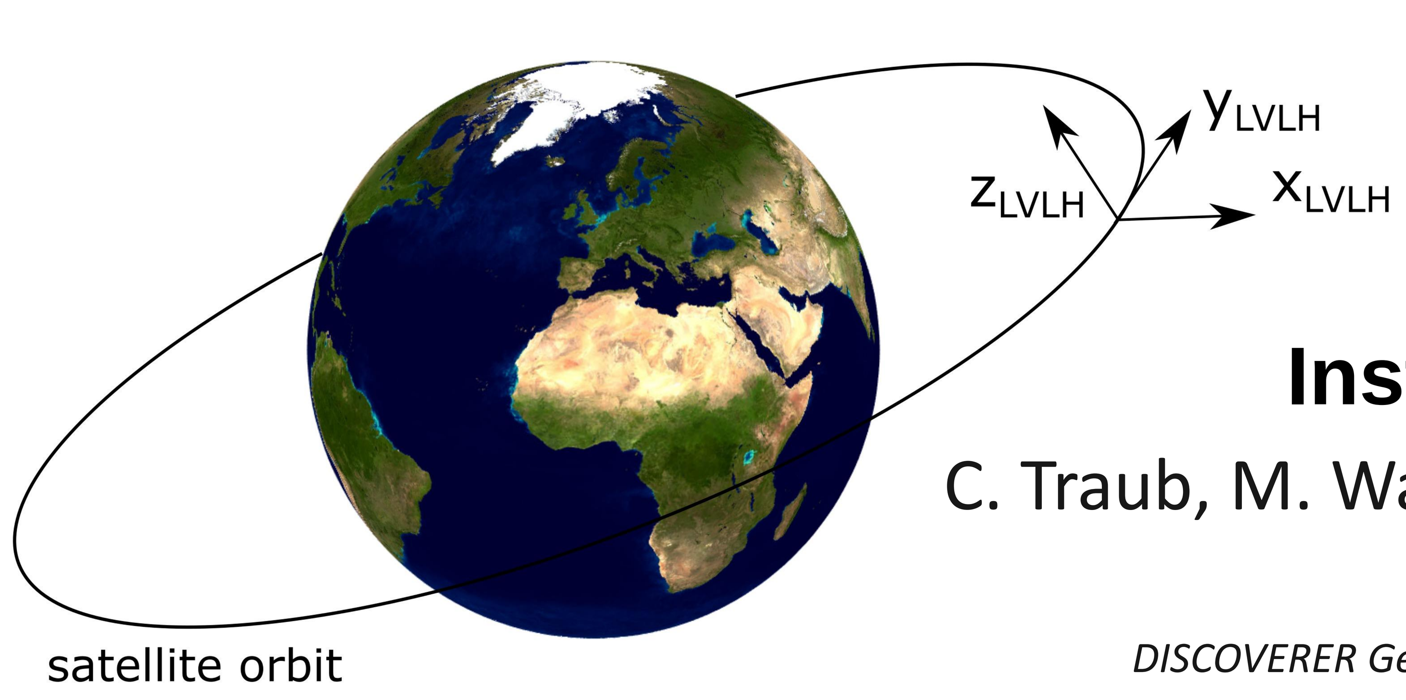
Benefits of reduced levels of energy accommodation for analytic rendezvous trajectories using aerodynamic forces



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Background and research goal

Very Low Earth Orbit (VLEO) offers the unique possibility for propellant less orbit, attitude and formation control via aerodynamic forces (DISCOVERER WP2):

- **Aerodynamic drag:** acts antiparallel to the relative velocity
- **Aerodynamic lift:** acts perpendicular to drag

→ Full controllability only with superposition of both forces

→ Increased lift forces via reduced levels of energy accommodation (DISCOVERER WP1&3)

Energy accommodation coefficient α: $\alpha = \frac{E_I - E_R}{E_I - E_W}$

Research goal: Quantify influence of energy accommodation on the rendezvous maneuver sequence [6]

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Preliminary work [1]

Analysis of the influence of energy accommodation on a robust rendezvous trajectory (circular orbit with 400 km altitude at 10° inclination) using aerodynamic forces using **Sentman's GSI model** [2] and the **NRLMSISE-00** [3] environment model for moderate solar and geomag. activity. Resulting (average) differential accelerations [10^{-5} m/s²]:

	High $\boldsymbol{\alpha = 1}$	***Medium*** $\boldsymbol{\alpha = 0.91}$	***Low*** $\boldsymbol{\alpha = 0.7}$
a_y	$a_y = 5.7$	$a_y = 6.6$	$a_y = 7.4$
a_x, a_z	$a_x = a_z = 0.49$	$a_x = a_z = 1.2$	$a_x = a_z = 2.19$

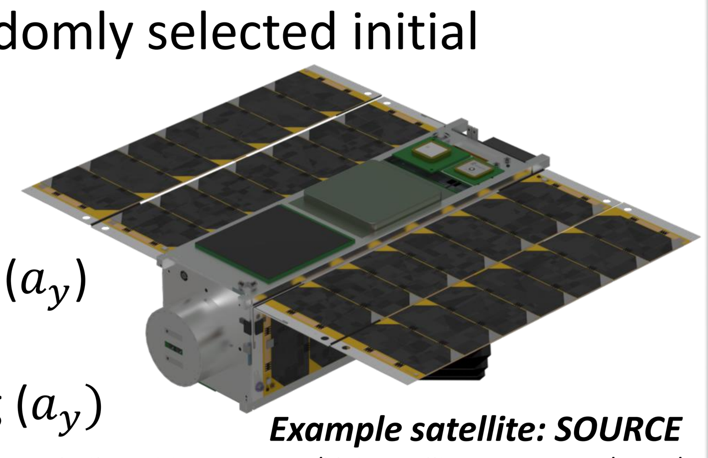
a_x = differential lift
a_y = differential drag
a_z = differential lift

Rendezvous trajectory algorithm [6,7]

- Analytic rendezvous trajectories using differential aerodynamic forces have a long heritage and are a simple means to gain insights in the methodology [4-6]
- Monte-Carlo based approach (10,000 runs with randomly selected initial conditions) allows for more general statements [7]

Rendezvous is achieved in three successive phases:

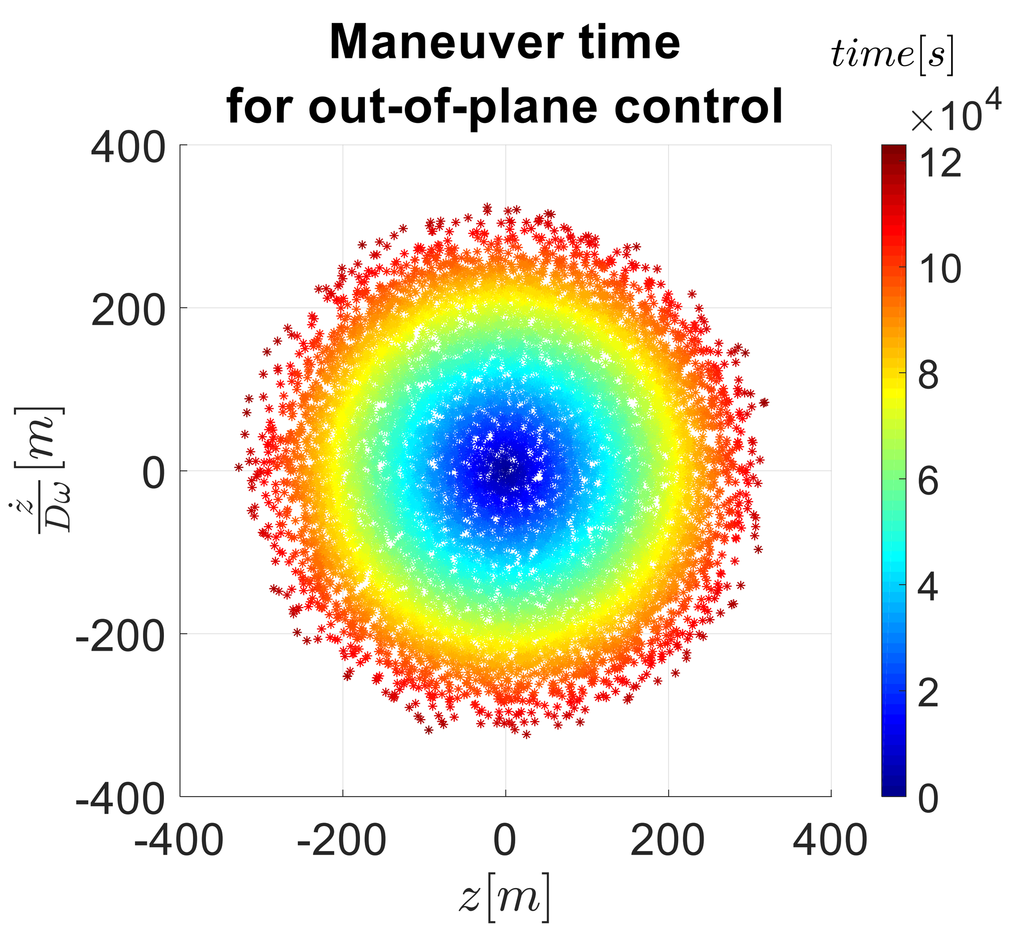
1. Average in-plane control via differential drag (a_y)
2. Out-of-plane control via differential lift (a_z)
3. Oscillating motion control via lift (a_x) **or** drag (a_y)

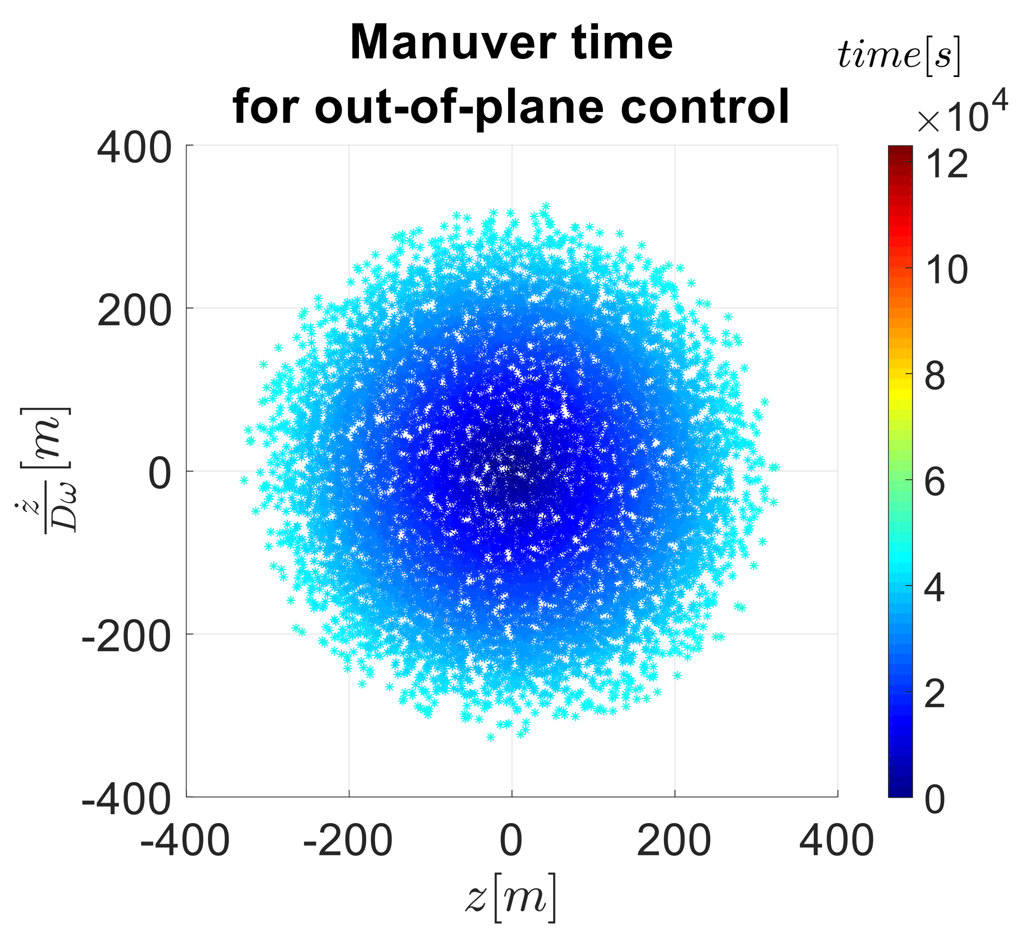


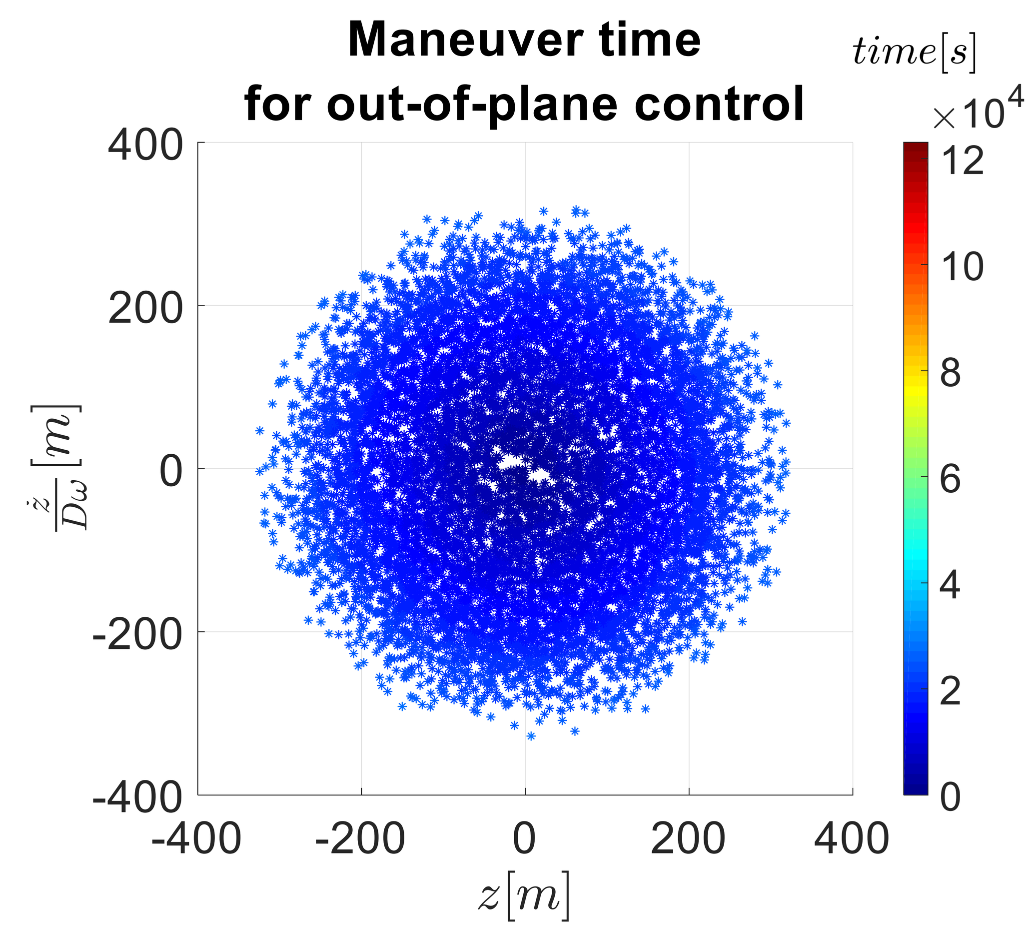
Example satellite: SOURCE

https://www.irs.uni-stuttgart.de/forschung/satellitentechnik-und-instrumente/kleinsatellitenprogramm/page/

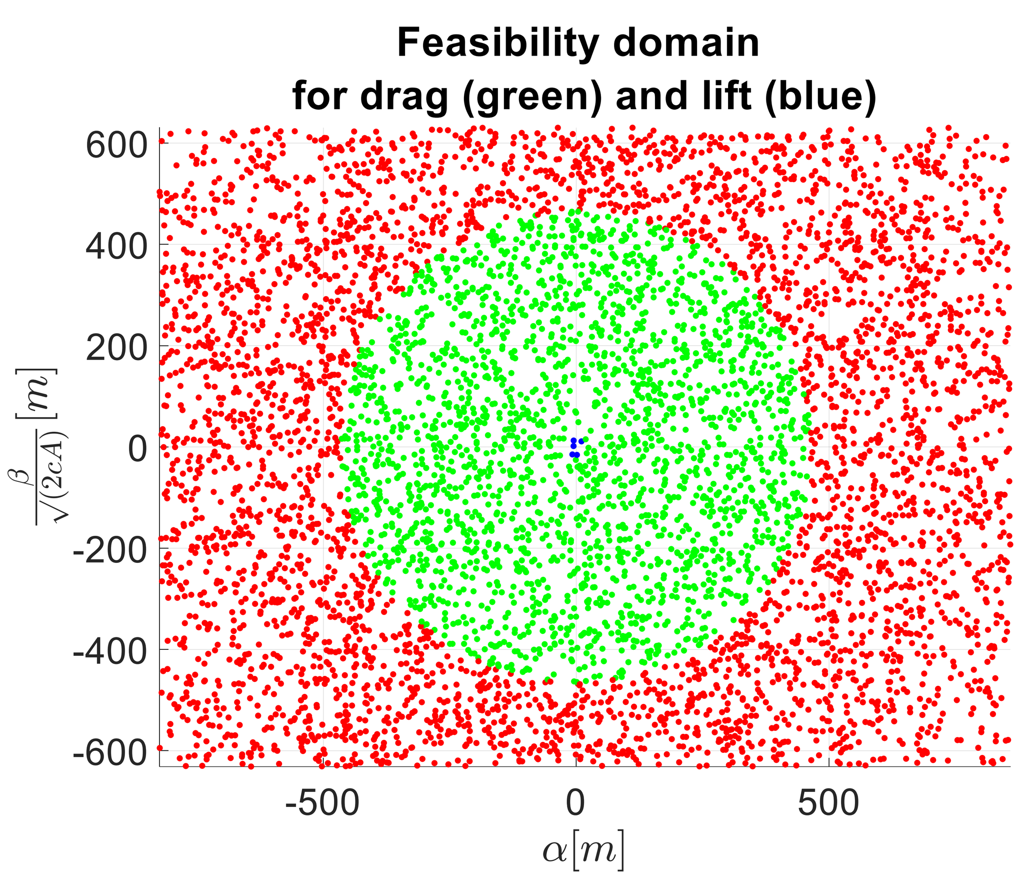
Results [8]

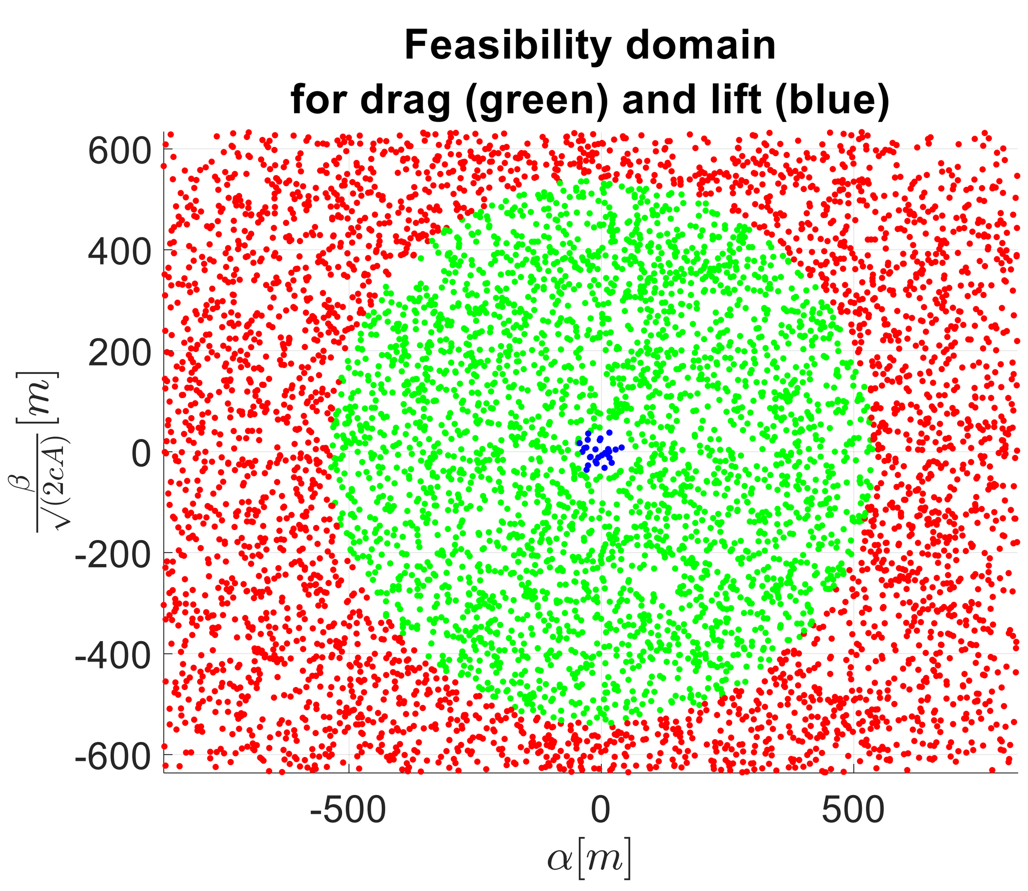


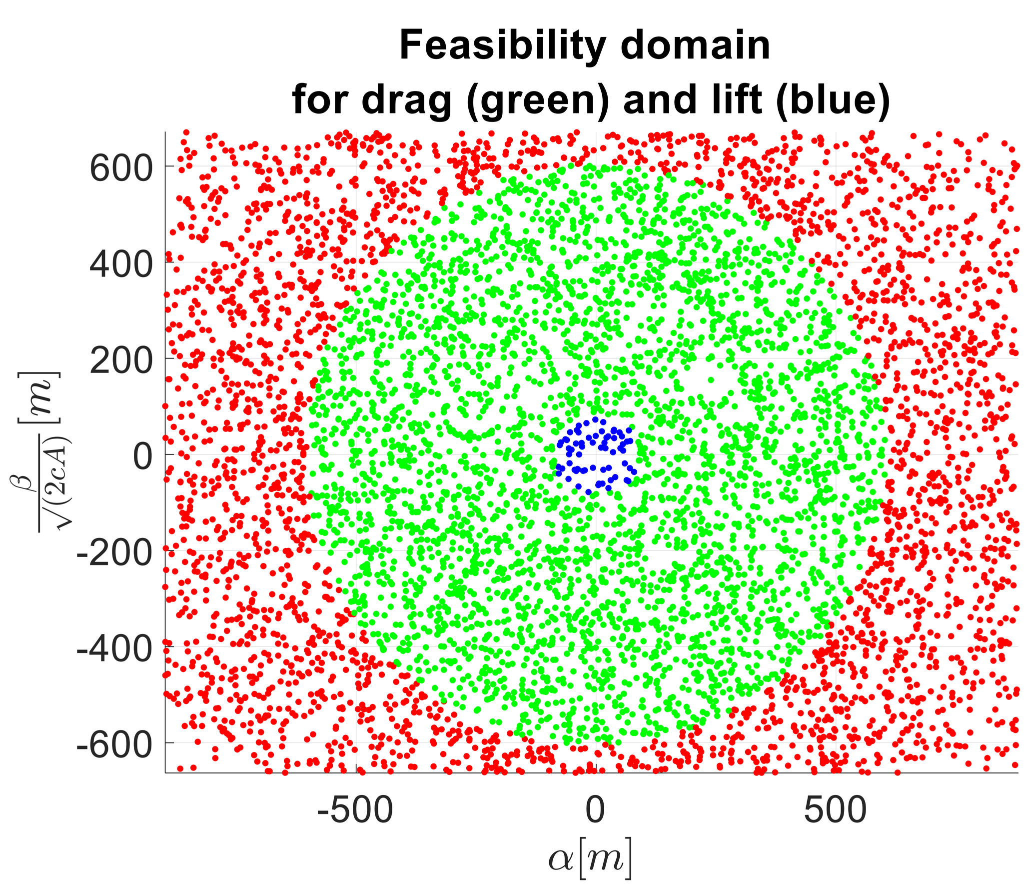




Maneuver times for second control phase for various initial conditions and high (left) medium (central) and low (right) levels of energy accommodation.







Initial condition of third control phase for which the algorithm leads to a successful rendezvous for high (left) medium (central) and low (right) levels of energy accommodation.

Conclusion

By decreasing the energy accommodation coefficient α from 1 to 0.7…

1. …the average time required to zero out the out-of-plane relative motion can be decreased by around 78%.
2. …the radius of the feasibility domain of lift can be increased by a factor of 4.3.

Conclusion: Low levels of energy accommodation are beneficial for lift based maneuvers. Still, drag is superior to lift for the in-plane control in any case.

Selected references

[1] C. Traub et al., "Influence of energy accommodation on a robust spacecraft rendezvous maneuver using differential aerodynamic forces," *CEAS Space Journal*, 2019. [2] L. H. Sentman, "Free molecule flow theory and its application to the determination of aerodynamic forces," *Technical Report, Lockheed Aircraft Corporation*, 1961. [3] J. M. Picone et al., "NRLMSISE-00 empirical model of the atmosphere: Statistical comparisons and scientific issues," *J. Geophys. Res.*, vol. 107, no. A12, SIA 15-1-SIA 15-16, 2002. [4] C. L. Leonard et al., "Orbital formationkeeping with differential drag," *Journal of Guidance, Control, and Dynamics*, vol. 12, no. 1, pp. 108–113, 1987. [5] M. Horsley et al., "Small Satellite Rendezvous Using Differential Lift and Drag," *Journal of Guidance, Control, and Dynamics*, vol. 36, no. 2, pp. 445–453, 2013. [6] X. Shao et al., "Satellite rendezvous using differential aerodynamic forces under J2 perturbation," *Aircraft Eng & Aerospace Tech*, vol. 87, no. 5, pp. 427–436, 2015. [7] B. Smith et al., "Investigation into the Practicability of Differential Lift-Based Spacecraft Rendezvous," *Journal of Guidance, Control, and Dynamics*, vol. 40, no. 10, pp. 2682–2689, 2017. [8] M. Walther et al., "Improvements to the Feasibility Range of Rendezvous Maneuvers using Aerodynamic Forces," in *Deutscher Luft-und Raumfahrtkongress*, Darmstadt, 2019.