Minimum-drag Satellite Geometries in VLEO

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Background:

- *Gas-surface interaction (GSI)*
- *Atmospheric models*
- *Drag modelling*
- *Shape optimisation*

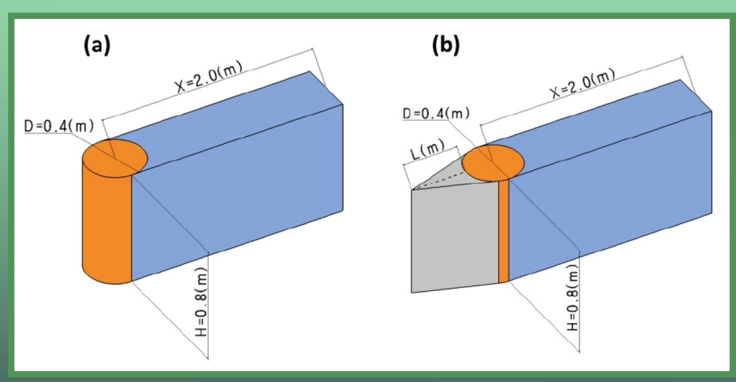
VLEO: Orbits below 450km altitude. The atmosphere has a significant effect on spacecraft. Most common surfaces become contaminated by adsorbed atomic oxygen.

Reflection is generally quasi-specular or diffuse, rather than specular, which affects the aerodynamic characteristics [1].

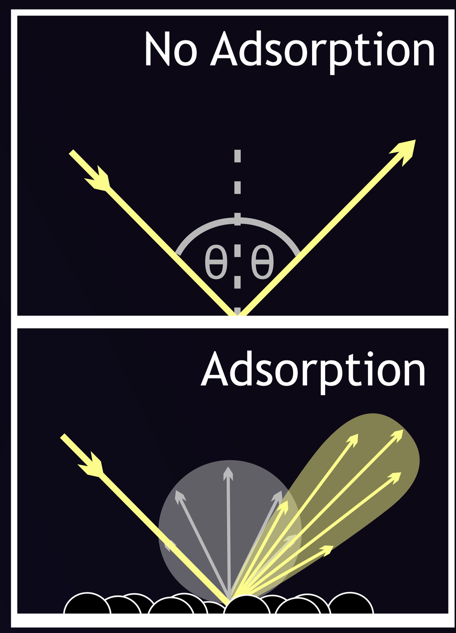
The choice of atmospheric model leads to uncertainties, based on factors such as geomagnetic and solar activity.

The uncertainty in GSIs and the atmospheric model leads to a lower limit on the uncertainty of drag coefficients.

Panel methods are the fastest way to calculate aerodynamic drag. In-house program which does this: ADBSat [2].



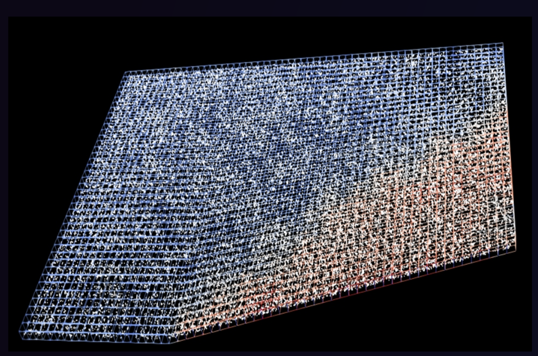
The figure above shows some shape optimisation that has already been investigated [1]. A common characteristic of the papers concerning this subject is a lack of continuity between configurations, with discrete shapes being investigated independently.



Top: Specular reflection
Bottom: Quasi-specular (yellow), and diffuse (grey) reflection

Direct Simulation Monte Carlo (DSMC):

- *Validation of panel methods*



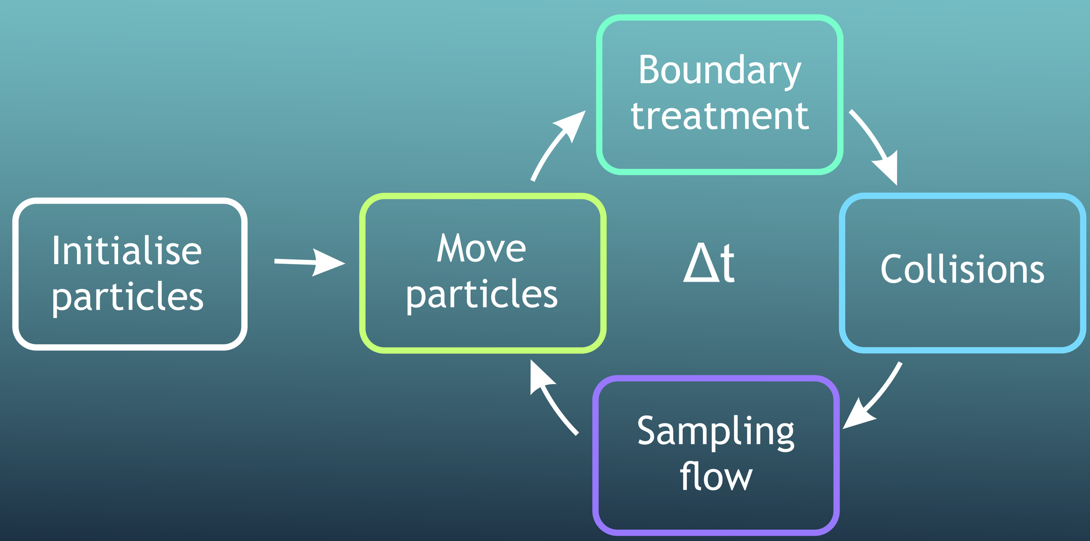
DSMC grid visualisation

A numerical method for modelling gas flows.
Models many real particles as one DSMC particle.

Calculates intermolecular and surface collisions probabilistically to solve the Boltzmann equations.

Choice of program: OpenFoam. Has been validated against analytical and discrete methods [3]
Usage: to validate and examine the limits of ADBSat.

Pros	*Cons*
Convex geometries	Computationally expensive
Multiple reflections	Time intensive
Fewer assumptions	



Computational Optimisation:

- *Optimisation algorithm choices*
- *3D optimisation problems*

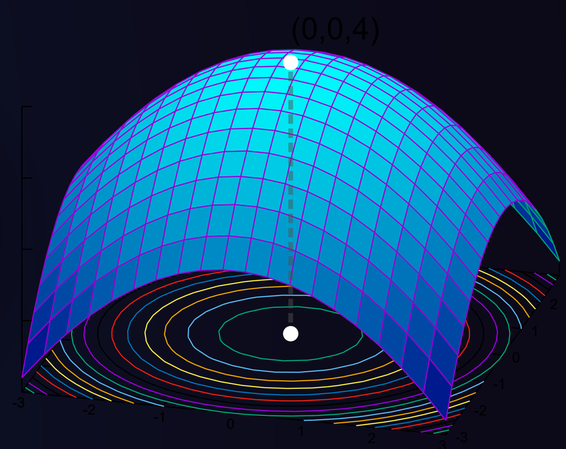
Many choices of optimisation algorithm:

- Gradient Methods
- Genetic Algorithms
- Particle Swarm Optimisation
- Hybrid Methods

No Free Lunch theorem: No one algorithm is better than any other for all problems. To pick the best one, you need an understanding of the underlying problem space and each specific search method [4].

Problem space is represented by some function f(**x**), where **x** is a vector of n optimisation variables.
Challenges in finding the optimal solution include:

- Developing an accurate mathematical representation of f(x)
- Handling many degrees of freedom in a reasonable computational time
- Identifying symmetries and other simplifying factors
- Handling constraints
- Devising a goodness-of-fit measure.



optimum point of a 3D solution space

Preliminary project plan:

- *Goal: to identify new optimised aerodynamic geometries.*

Satellite shape alteration

Validate ADBSat for complex geometries → Use DSMC and analytical results to find limits of ADBsat, i.e. cases where it significantly deviates from solution.

Formulate a mathematical description of shape optimisation problem → Represent the problem and its solution in mathematical terms using set theory. Determine which way to best search the solution set for the optimum solution.

Write an optimisation routine which attempts to find the best solution to the problem → Search for the optimum low-drag solution globally, subject to practical constraints. Integrate the geometry optimisation with ADBSat to perform the drag modelling calculations.

Establish a method for finding lowest-drag configurations subject to constraints → Biggest challenges: Many degrees of freedom, computational expense, handling constraints, establishing a goodness-of-fit measure.

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[1] J.H. Park, R.S. Myong, D.H. Kim and S.W. Baek, "Aerodynamic shape optimization of space vehicle in very-low-earth-orbit", AIP Conference Proceedings, vol. 1628, pp. 1331, 2014. doi: 10.1063/1.4902745.
[2] D. Mostaza-Prieto, "Characterisation and Applications of Aerodynamic Torques on Satellites", PhD thesis, University of Manchester, 2017.
[3] T.J. Scanlon, E. Roohi, C. White, M. Darbandi, and J.M. Reese, "An open source, parallel DSMC code for rarefied gas flows in arbitrary geometries", Computers & Fluids, vol. 39 pp. 2078-2089, 2010. doi: 10.1016/j.compfluid.2010.07.014.
[4] X.S. Yang, "Mathematical Analysis of Nature-Inspired Algorithms". In: X. S. Yang (ed), "Nature-Inspired Algorithms and Applied Optimization". Studies in computational intelligence, vol. 744, pp 1-25. Cham, Switzerland: Springer International Publishing AG, 2018.