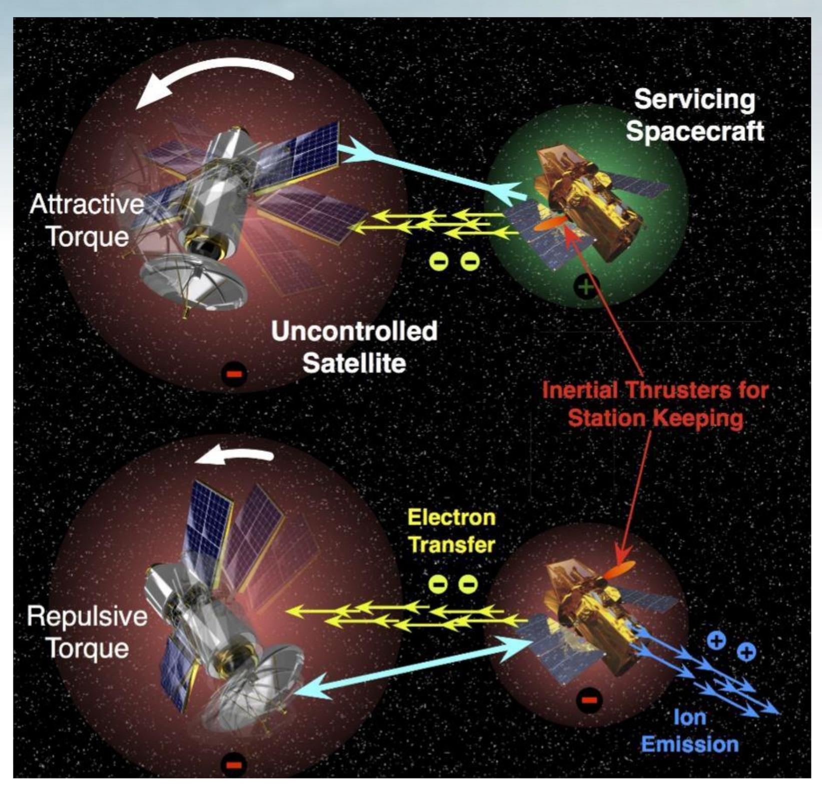
May the Electrostatic Force be With You: Charged Spacecraft Models

Christine Reilly, Dr. Hanspeter Schaub and Trevor Bennett

Aerospace Engineering Sciences, University of Colorado Boulder

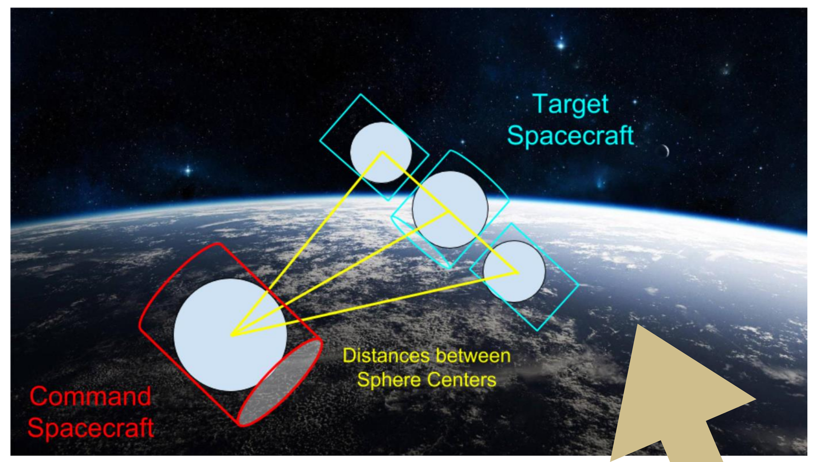


Electrostatic Actuation in Space

Non-functional spacecraft in geosynchronous orbit are at risk of being struck by **space debris** and becoming debris themselves. Many current proposed strategies for debris removal involve physical contact between spacecraft – a dangerous maneuver. **Touchless** electrostatic actuation can be achieved with a command spacecraft that **remotely charges** the target with an electron gun. This method would allow **safe** detumbling, docking, servicing, and debris removal using Coulomb forces and torques, but the complex dynamics require **real-time** electrostatic computations.

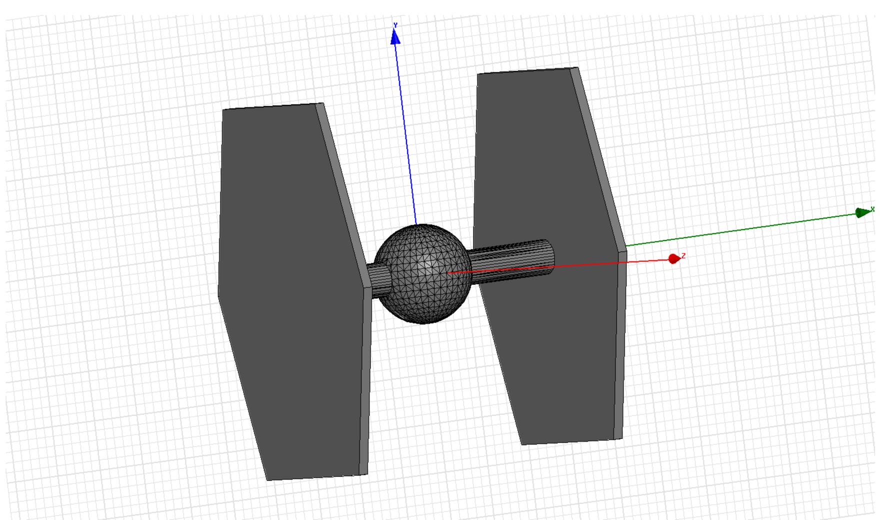
Inputs

- **Voltage** of each spacecraft
- **Radii** and **distances** between spheres

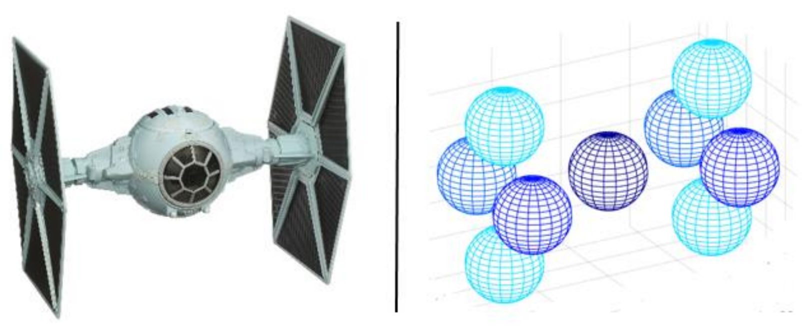


Electrostatic Models

Finite Element Analysis (FEA) VS The Multi-Sphere Method (MSM)

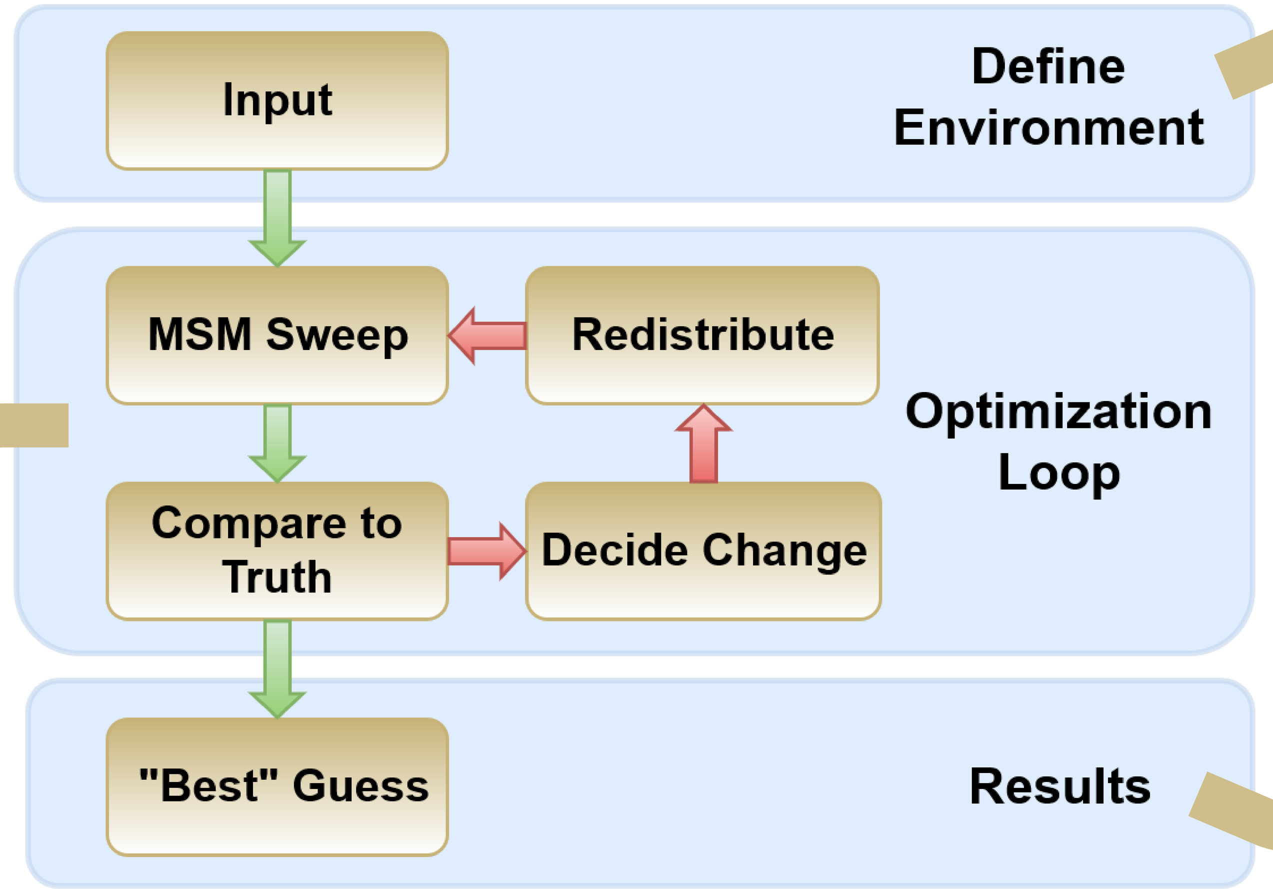


Commercially available software has **high accuracy** but takes minutes to run so it is used as a **truth model** to validate MSM.



MSM represents spacecraft with a distribution of theoretical conductive spheres. Although less accurate than FEA, it **runs in 1/50 second**. MSM needs an optimizer that will allow it to support complex spacecraft geometries.

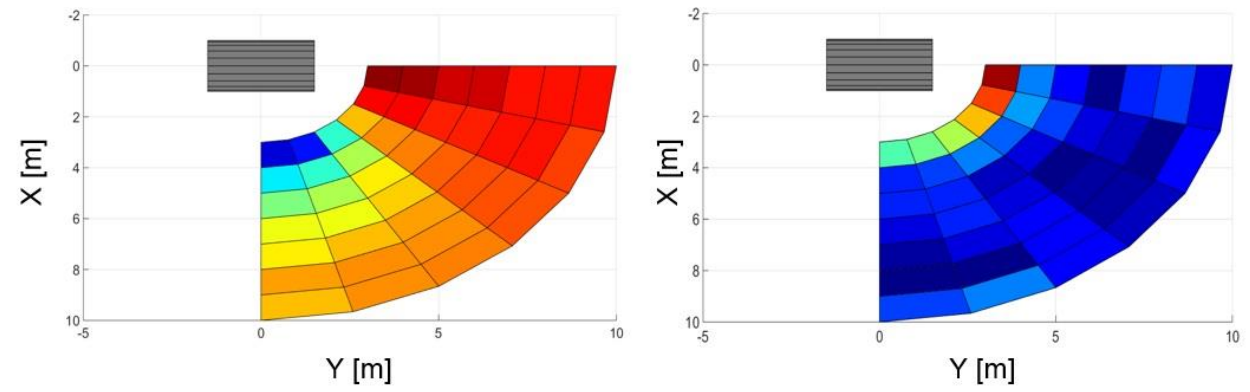
Optimizing Sphere Distributions



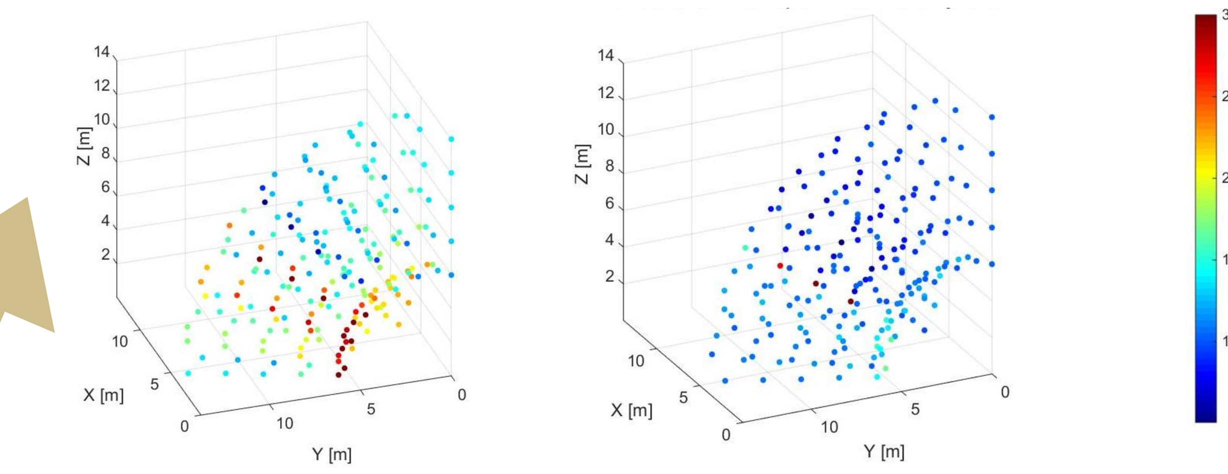
Results

Un-optimized versus optimized cost

A three-sphere cylinder is evaluated with a two dimensional sweep in one quadrant.



A nine-sphere Tie Fighter, which has less symmetry, is evaluated with a three dimensional sweep in one octant.

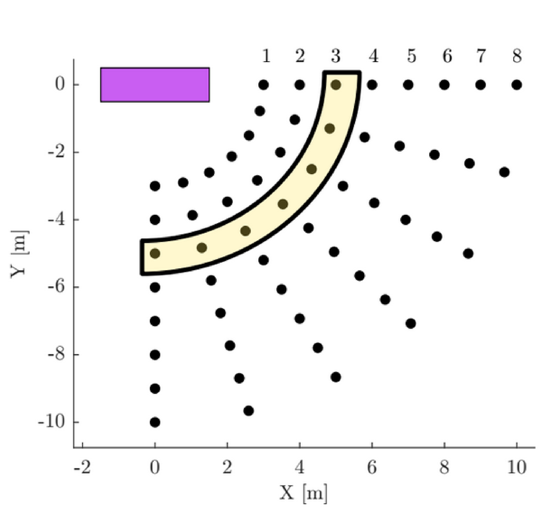


Red represents high cost and blue represents low cost. Optimization **reduces the average error to 1%.**

Comparing Models

MSM Sweep

- Place command spacecraft at **different distances and orientations**
- Find charge on each sphere using voltages and position-dependent capacitance
- Calculate forces and torques with Coulomb's law



Cost Calculations

- Calculate **normalized vector difference** between MSM and FEA results at each sweep point
- Weight the differences in force, torque, and capacitance and sum to get final **cost**
- Cost quantifies the accuracy of each sphere distribution

$$\Delta F = \frac{|\boldsymbol{F}_{MSM} - \boldsymbol{F}_{FEA}|}{|\boldsymbol{F}_{FEA}|} \quad \Delta T = \frac{|\boldsymbol{T}_{MSM} - \boldsymbol{T}_{FEA}|}{|\boldsymbol{T}_{FEA}|} \quad \Delta C = \frac{C_{MSM} - C_{FEA}}{C_{FEA}} \quad Cost = [W_F \; W_T \; W_C] \begin{bmatrix} \Delta F \\ \Delta T \\ \Delta C \end{bmatrix}$$

Future Work

- Test additional complex spacecraft geometries for both command and target spacecraft
- Determine initial sphere placement from CAD or .stl file

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Thank you!