Numerical Determination of Spacecraft Formations in Deep Space

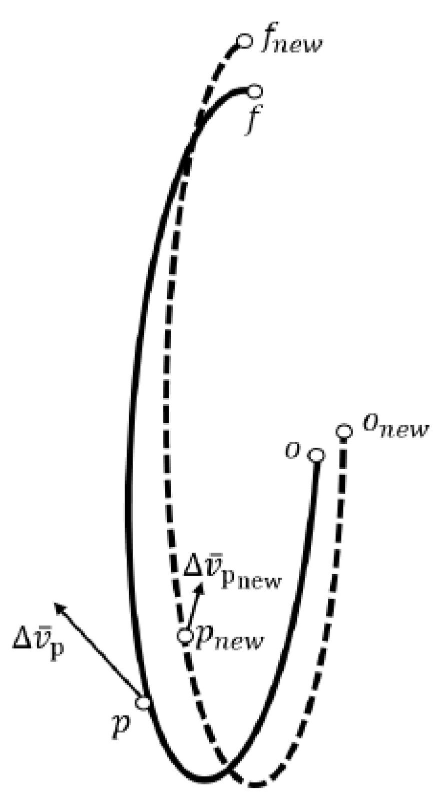
Donna Jennings
Department of Mechanical & Aerospace Engineering

Background

- Spacecraft formations allow for distributed spacecraft technologies, mission flexibility, and mission redundancy
- Thorough understanding of the relative dynamics is necessary to perform trajectory planning, meeting mission requirements, and collision avoidance
- Deep space applications include servicing monolithic spacecraft and providing a communication link for deep space assets
- **Goal** – Identify natural relative trajectories at the L_1 and L_2 libration points

Two-Level Differential Corrector

- Initialize with patch points of desired trajectory
- Level 1 Differential Corrector: Iterative process to determine continuous path
- Level 2 Differential Corrector: Minimizes all velocity discontinuities



Initial Path and New Path to Reduce Velocity Discontinuity

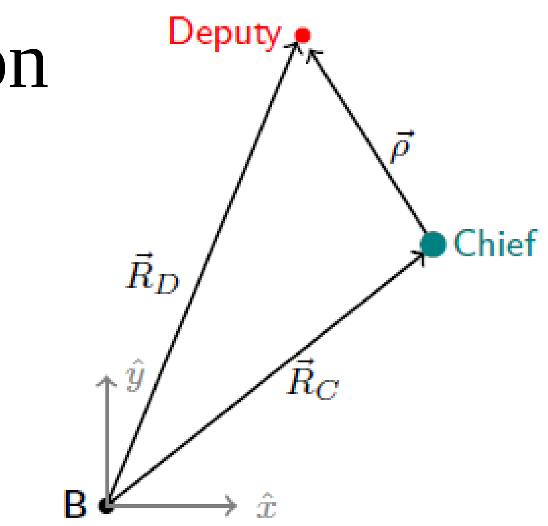
Method

Approximate Relative Trajectory → Two-Level Differential Corrector → Natural Continuous Formation → Monte Carlo Simulation → Analysis

- Utilized a linear approximation to initialize relative trajectory

$$\rho_x = -A_x \cos(\lambda t + \phi)$$
$$\rho_y = kA_x \sin(\lambda t + \phi)$$
$$\rho_z = A_z \sin(\nu t + \psi)$$

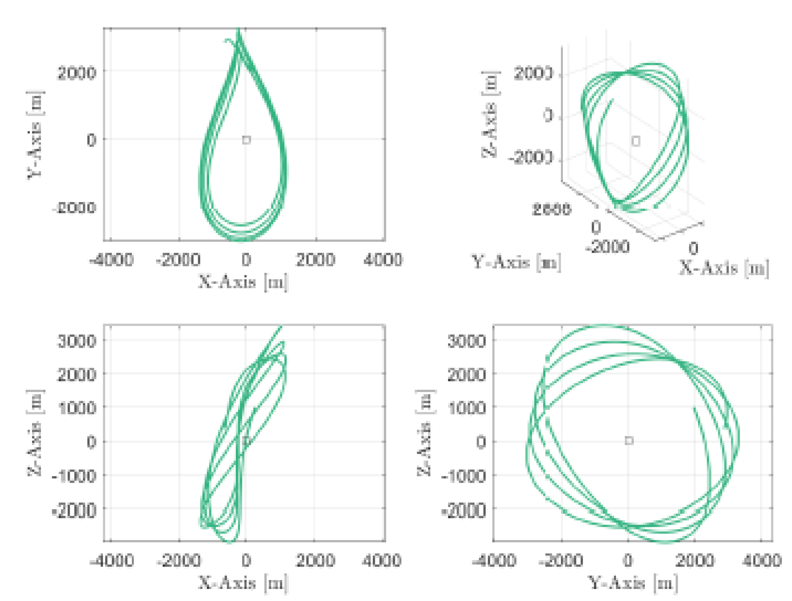
- Implemented a shooting method with a two-level differential corrector to identify a natural continuous formation
- Performed Monte Carlo analysis:
  - Independent Variables: Injection error, relative navigation error, and actuator error
  - Dependent Variable: Amount of propellant needed to maintain formation flight



Relative Vector Geometry

Results

- Desired relative position of 3 km
- Numerical trajectory converged after 33 iterations
- Patch points moved an average of 0.6 km and 0.004 km/s
- Monte Carlo simulation to determine stationkeeping costs
  - Linear quadratic regulator utilized for stationkeeping
  - 1,000 samples
  - Impulsive maneuvers



Final Converged Relative Trajectory

Stationkeeping Results of Monte Carlo Simulation

Trajectory Type	Mean ΔV [m/s]	Standard Deviation [m/s]
Numerical	0.475	0.027
Linear	1.802	0.412

Conclusions

- Demonstrated a numerical approach to finding natural relative formations in deep space
- Compared the numerical trajectory to the established linearized solution
  - Numerical trajectory has lower stationkeeping costs
  - Linearized solution drifts away from desired quicker than numerical trajectory

Future Work

- Incorporating higher fidelity dynamic models of spacecraft motion
- Investigating different control techniques and their effect on stationkeeping costs
- Identifying other natural and nonnatural formations possible in deep space
- Managing formation initialization and reconfiguration
- Accommodating thrust-limited propulsion systems

Acknowledgements

- Office of Graduate Studies – CDF