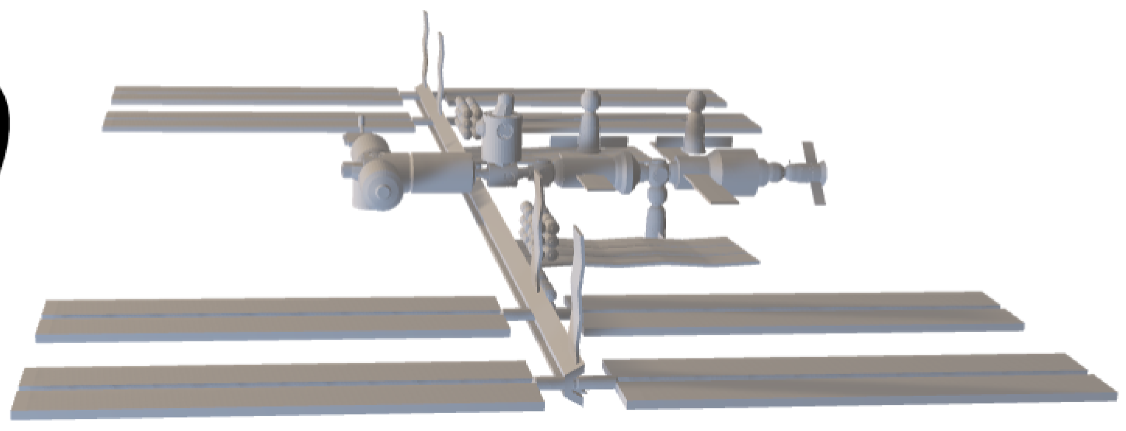
PyRPOD

Python Based Analysis for **R**endezvous, **P**roximity, **O**perations, and **D**ocking Maneuvers



Dr. Michael Kinzel
Associate Professor, Aerospace Engineering
Director of CFAL
Michael.Kinzel@erau.edu

Overview

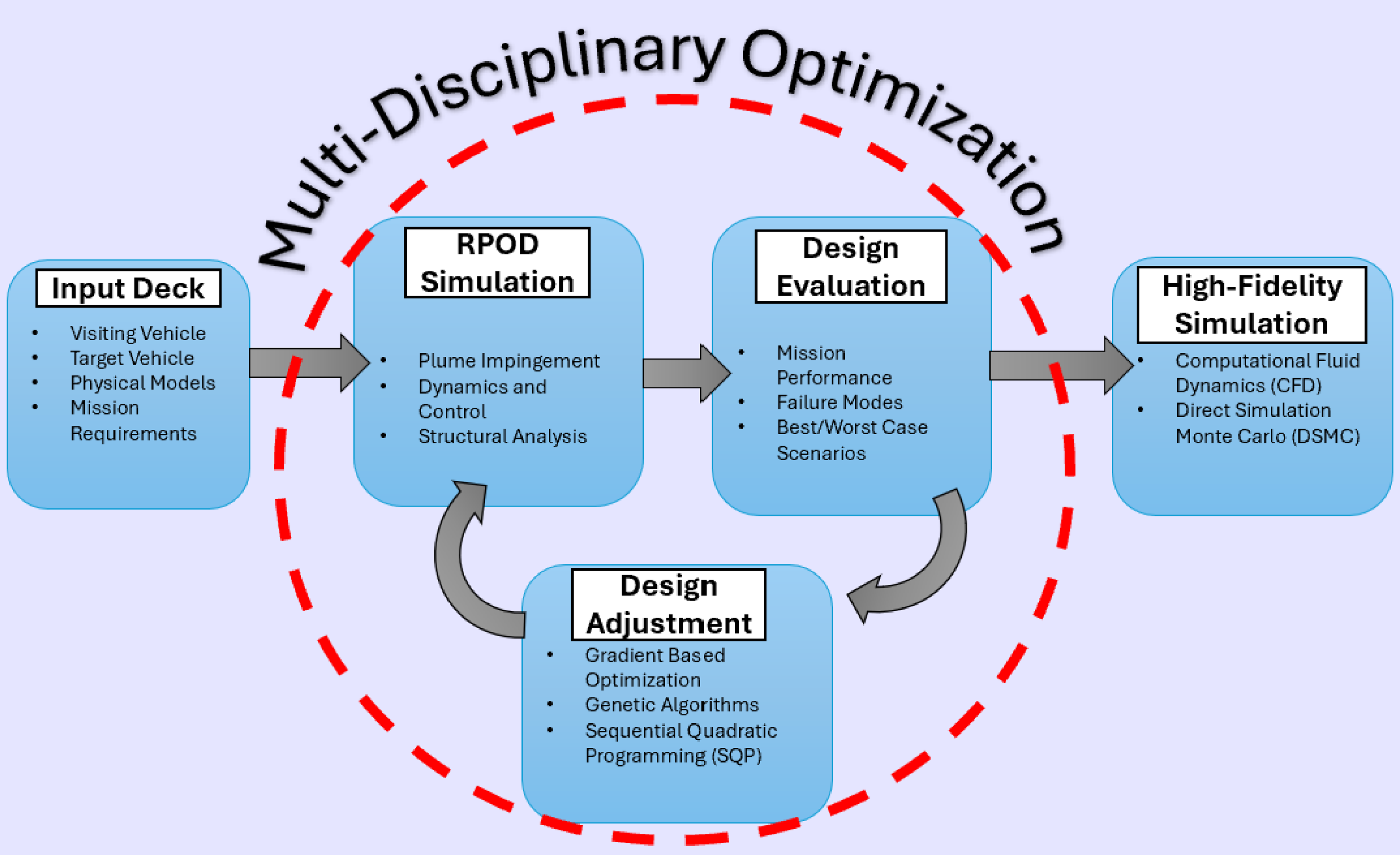
What is PyRPOD?

An open-source Python library for multidisciplinary simulation of spacecraft during rendezvous, proximity, operations, and docking maneuvers.

Why is PyRPOD useful?

Allows for rapid design iteration of space missions. Enables engineers to save time and computational resources by avoiding unnecessary high-fidelity simulations.

Analysis Workflow



Plume Modeling

Why is Plume Strike modeling important?

Thruster plumes can damage spacecraft surfaces and severely degrade operational safety

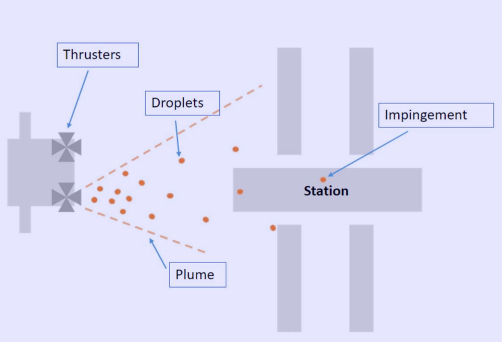
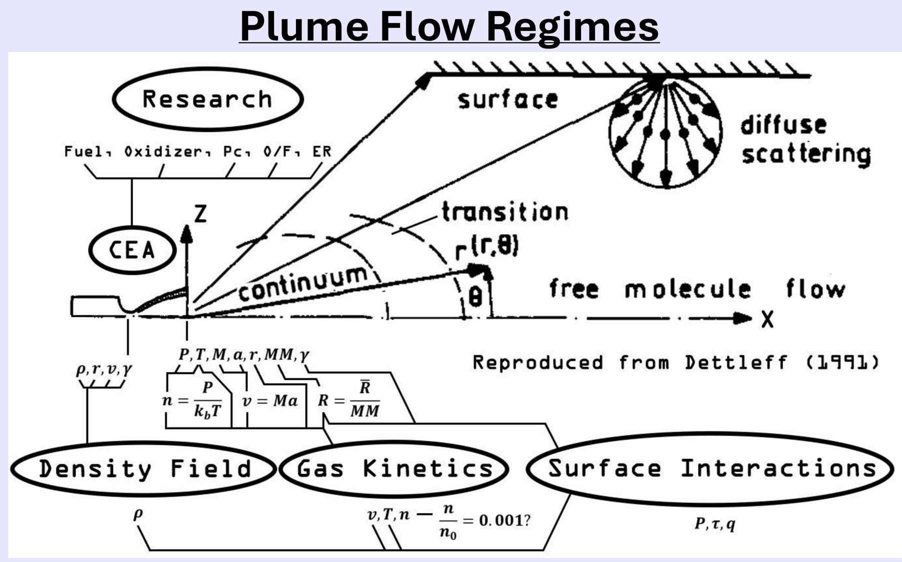


Figure 1. Plume Impingement

Plume Flow Regimes

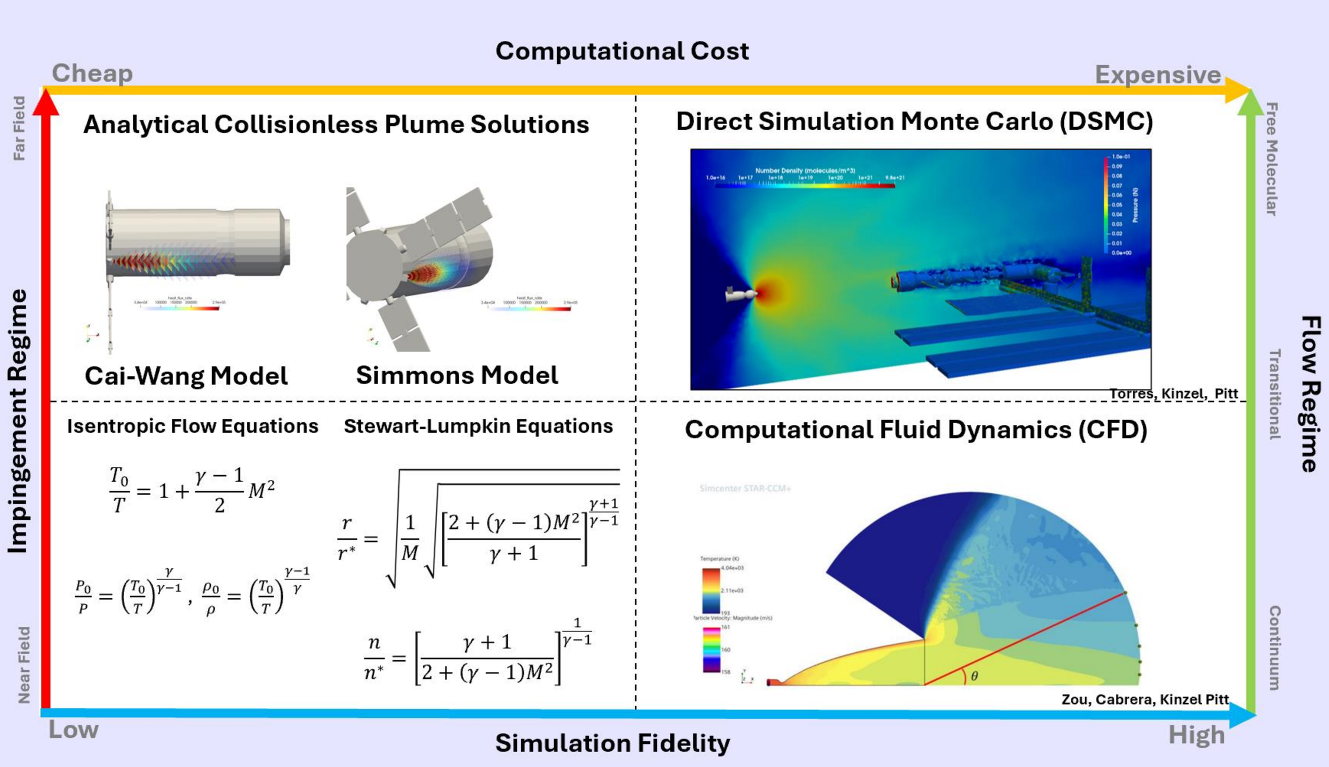


Knudsen Number

$$Kn = \frac{\lambda}{L} = \frac{\text{mean free path}}{\text{characteristic length}}$$

Flow Regimes

$Kn < 0.01$	Continuum Flow
$0.01 < Kn < 0.1$	Slip Flow
$0.1 < Kn < 10$	Transitional Flow
$Kn > 10$	Free Molecular Flow



Who We are Looking For

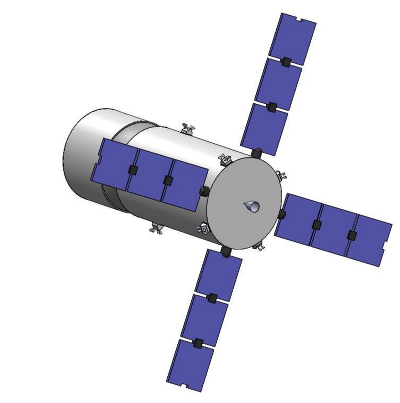
- **Software engineering** students interested in developing open-source software.
- **Mechanical and Aerospace engineering** students interested in rarefied plume physics, GNC, orbital mechanics, and mission planning, computational fluid dynamics (CFD) for developing advanced physics modeling.

If interested, please reach out to:
Andy Torres at torresfa@my.erau.edu.

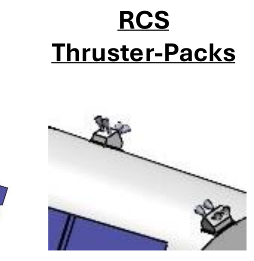
Case Study: Gateway Space Station

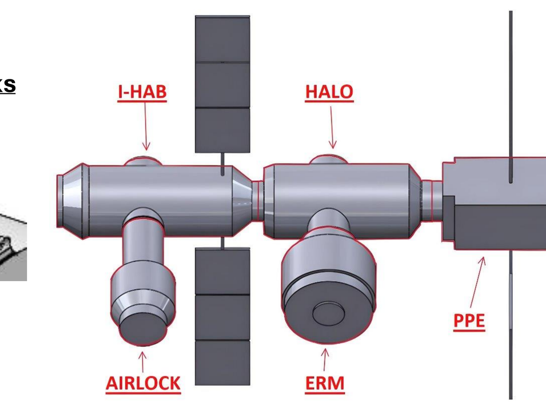
Objective

Design the RCS configuration for a Logistics Module tasked with delivering supplies to the Gateway Space Station.



Logistics Module





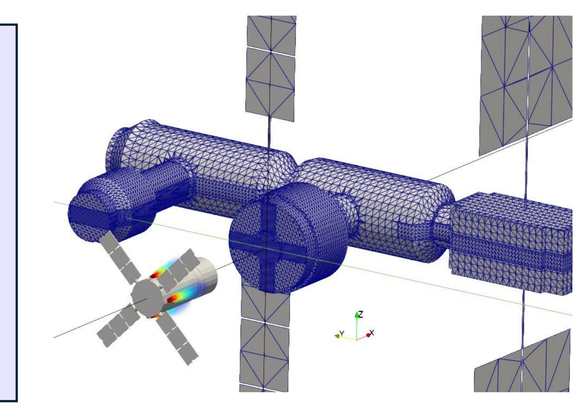
Gateway Geometry

Design Variables

- Thruster Type
- Thruster-pack positioning
- Thruster Cant Angle

Design Constraints

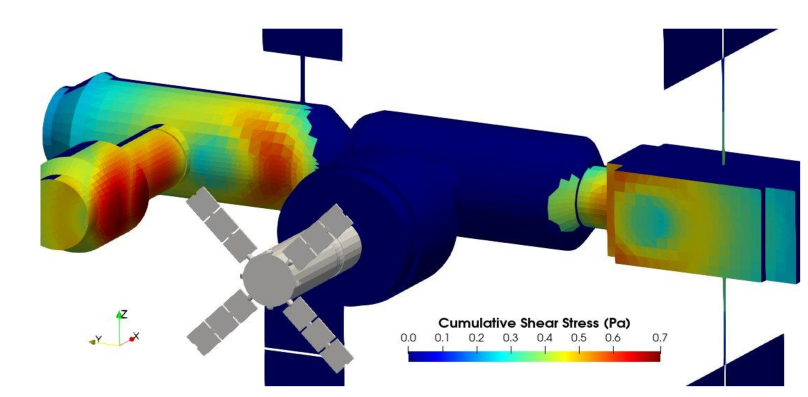
- Fuel Usage
- Plume Impingement
  - Pressure
  - Heat Flux
  - Shear
- Factory of Safety

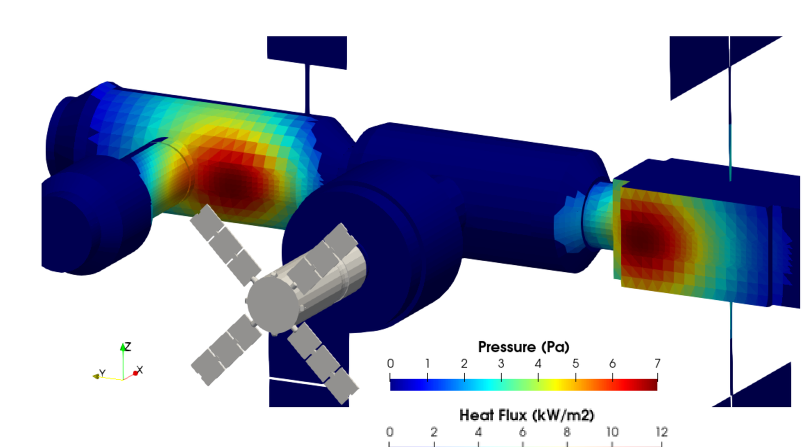


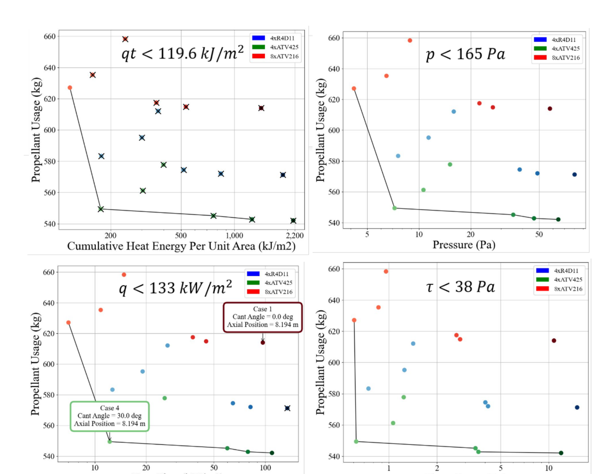
Results

Optimal Solution

Variable Name	Value
Thruster Type	ATV425
Number of Thrusters	4
Cant Angle	30°
Shear Stress	$0.7\ Pa \ll 38\ Pa$
Pressure	$7\ Pa \ll 165\ Pa$
Heat Flux	$12\ {}^{kW}/_{m^2} \ll 133\ {}^{kW}/_{m^2}$
Heat Energy Per Unit Area	$186\ {}^{kJ}/_{m^2} \gg 119\ {}^{kJ}/_{m^2}$







Conclusion

- Pareto fronts are used to illustrate trade-off performance between design variables.
- On average mission requirements see order of magnitude improvement through a simple trade study analysis.
- Best design almost passes all design constraints.

Future Work

Mission Design and Optimization

- Thruster Orientation
- Trajectory Optimization
- Control Design
- Orbit Determination
- Additional Trade Studies
  - Approach Trajectories
  - JFH Sequencing

Development of Physical Models

- Plume Induced Dynamics
  - Integration of 6-DOF solver
  - Vibrational Analysis
- Analysis of Chemical Reactions
- Multiphase Plumes and Particle Transport
  - Surface Erosion and Damage
- High-fidelity simulations

Software Engineering

- API Development
- GUI Development
- Modular and Professional Code Development
- Adaptation for HPC systems
  - CPU and GPU
- Data Modeling (AI/ML)

Future Applications

- Orbital Debris Mitigation
- In-Orbit Servicing
- In-Orbit Assembly
- Plume Surface Interaction (PSI)

Contributors

Janice Zou (UCF & Stanford): Near Field Plume Models
Camila Cabrera (FIU): Near Field Plume Models
Nicholas Palumbo (UCF): PyRPOD Developer, Far Field Plume Models
Juan P. Roldan (UCF & ERAU): PyRPOD Developer, Far Field Plume Models
Andy Torres (UCF & ERAU): PyRPOD Developer, Far Field Plume Models
Jonathan Pitt (NASA-KSC): NASA SME providing technical guidance