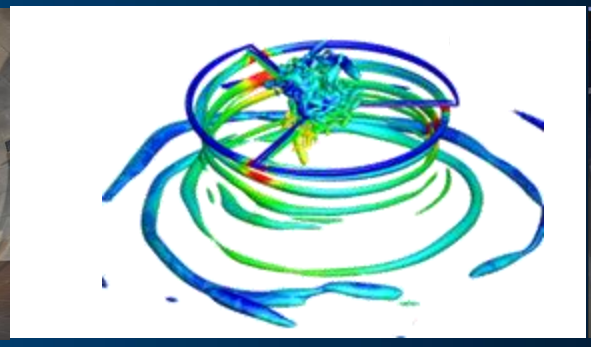
On the Application of an Actuator Line Model for Rotorcraft Outwash Predictions

Nicholas Peters, Dorsa Shirazi

Advanced Modeling & Simulation (AMS) Seminar Series
NASA Ames Research Center, June 26th, 2025







Overview

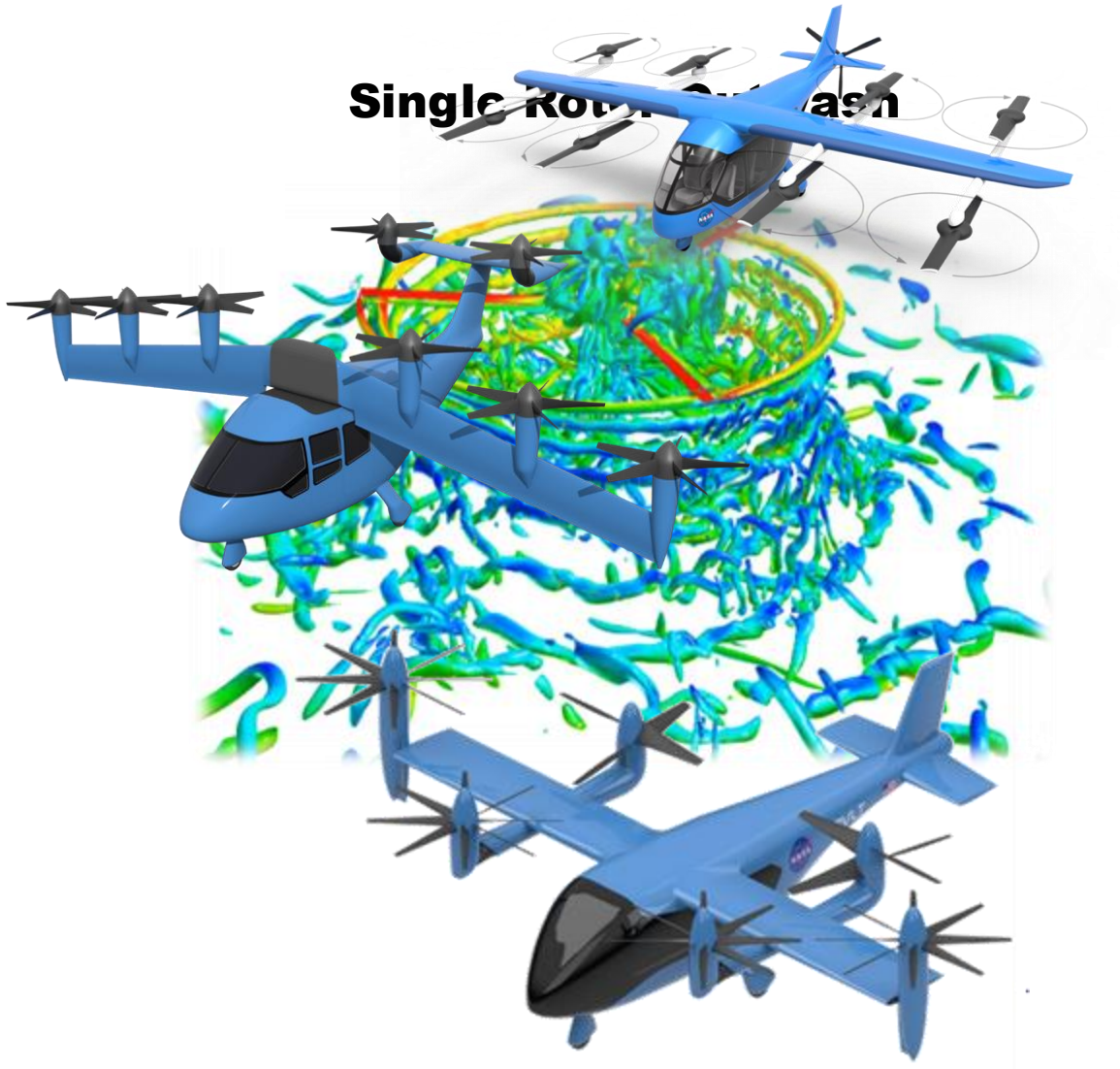
- **Background**
- **Study Overview**
- **Results and Discussion**
- **Concluding Remarks**

Challenges for AAM Outwash Predictions

- **Outwash has been a focal point of study within the rotorcraft sector for several decades.**
  - Limited experimental data for AAM rotor configurations

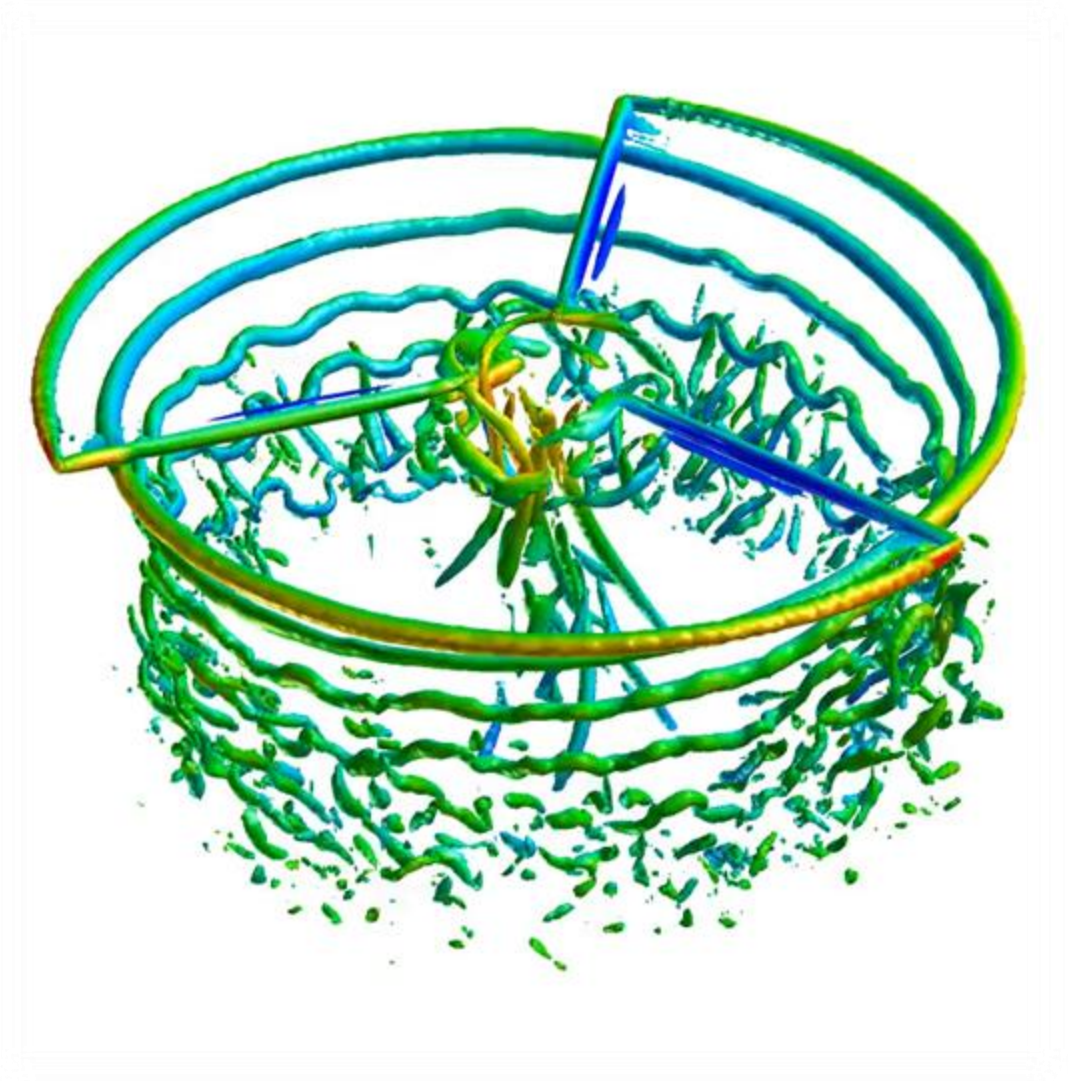
- **With the advent of Advanced Air Mobility (AAM), future rotorcraft are proposed to have multi-rotor configurations.**

- **In the absence of experimental data, engineers are pushed to rely on costly, high-fidelity blade-resolved CFD simulation.**



Implementation of an Actuator Line Model

- **A blade element theory (BET) model was implemented in OVERFLOW.**
  - Induced velocities extracted from the CFD flow field
  - Rotor loads converted to energy/momentum source terms
- **Advantage is potentially faster CFD simulations!**
  - Less mesh for rotors, larger time steps
- **Disadvantage is reduced fidelity rotor load predictions.**
  - Relying on BET rather than first principles for rotor load predictions

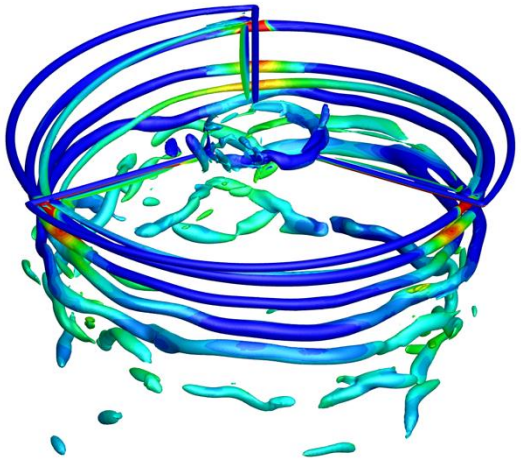


Overview

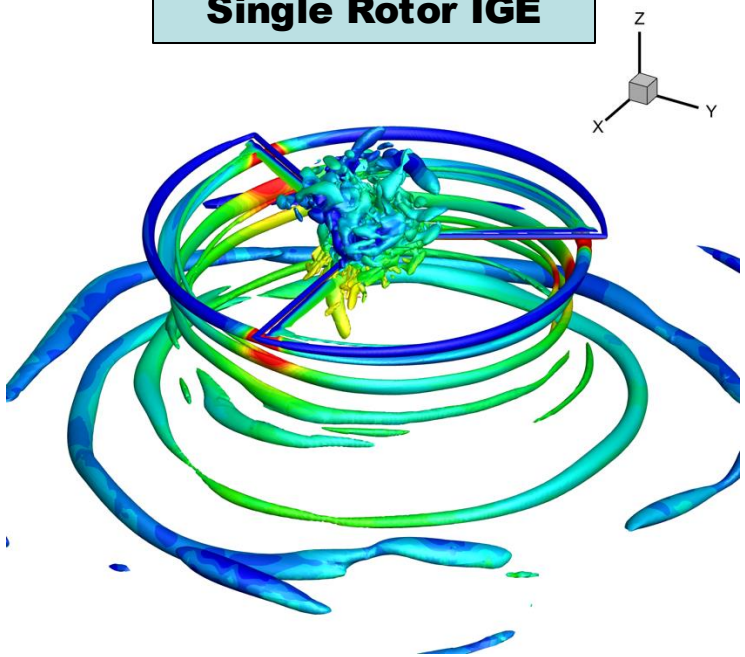
- Background
- Study Overview
- Results and Discussion
- Concluding Remarks

Objective of Study

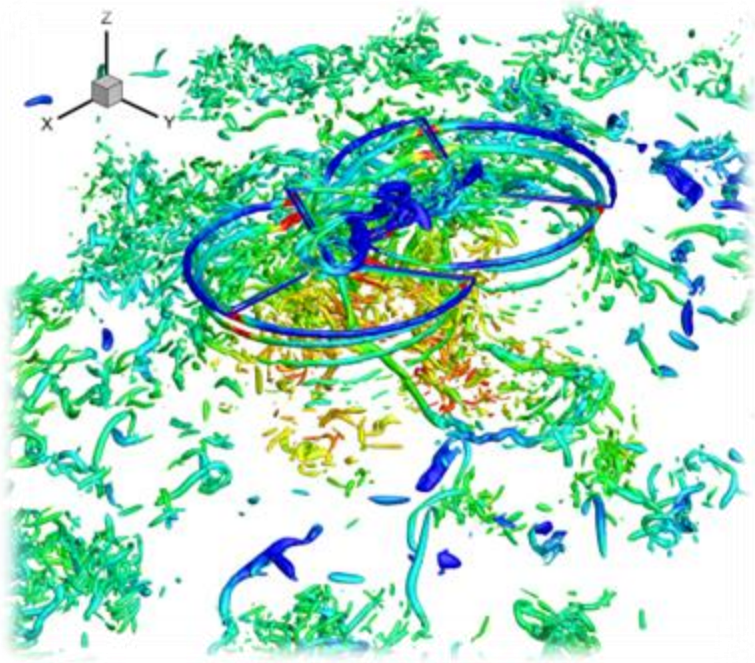
Single Rotor OGE



Single Rotor IGE



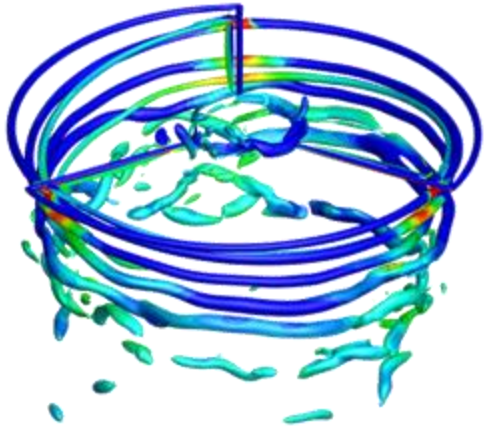
Tandem Rotor IGE



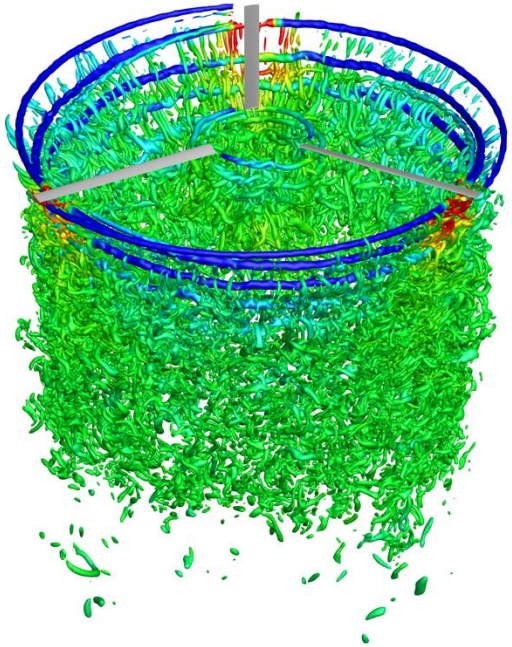
- **Develop an actuator line model within the NASA OVERFLOW CFD code to obtain time-averaged outwash predictions.**
  - Validated against existing experimental measurements across three validation cases: single rotor Out-of-Ground Effect (OGE), single rotor In-Ground Effect (IGE), and tandem rotor IGE

Research Questions

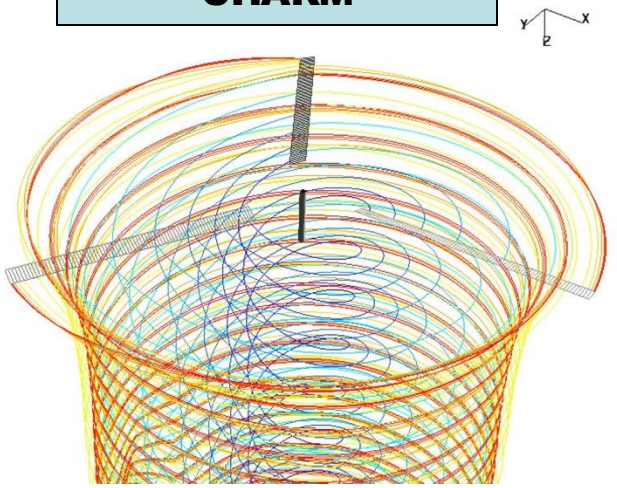
Actuator Line



Blade Resolved



CHARM

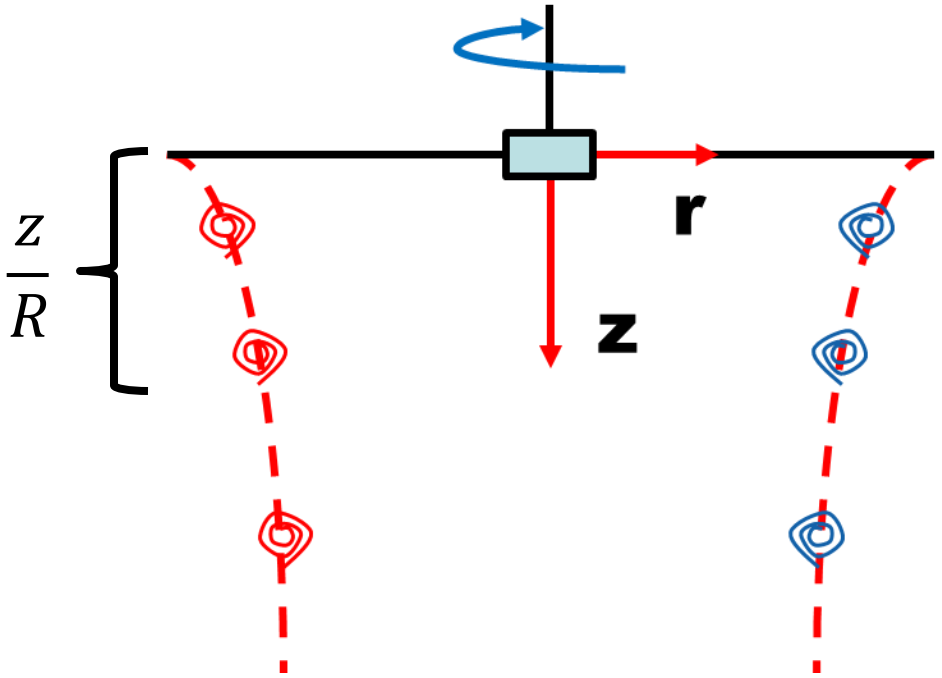


- **Compared to blade-resolved CFD simulation, what is the fidelity loss and computational savings of actuator line-based CFD modeling for time-averaged outwash predictions?**
- **How does computational cost and modeling fidelity compare between comprehensive analysis and actuator line-based CFD?**

Metrics For Comparison – Downwash

- **For CFD solutions, 20 rotor revolutions were completed to build an initial startup wake.**
  - 10 additional revolutions were completed for averaging

- **Time-averaged wakes compared at four radial distances beneath the rotor's hub.**



Paper: Ramasamy, Manikandan, and Gloria K. Yamauchi. "Using model-scale tandem-rotor measurements in ground effect to understand full-scale CH-47D outwash." *Journal of the American Helicopter Society* 62.1 (2017): 1-14.

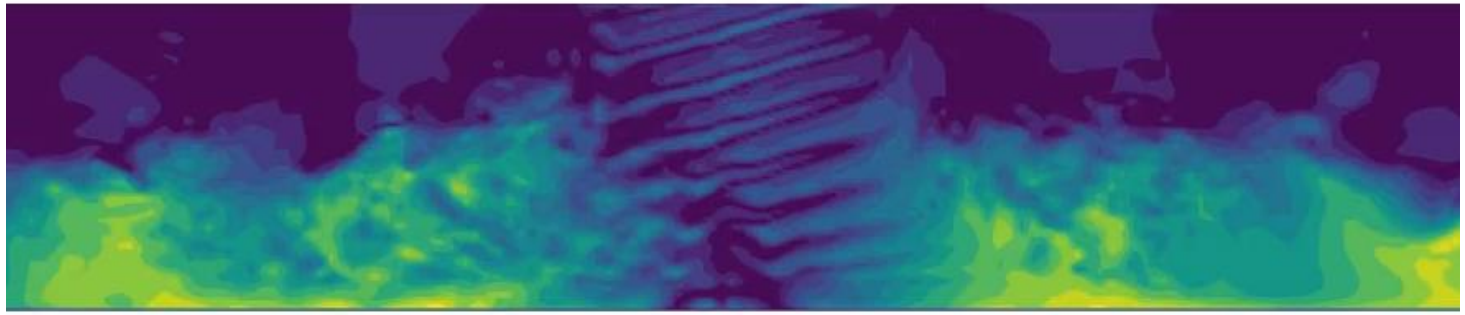
Metrics For Comparison – Outwash

- **For CFD solutions, 30 rotor revolutions were completed to build an initial startup wake.**
  - 10 additional revolutions were completed for averaging

- **Two metrics for comparison are presented today.**
  - Time-averaged maximum outwash versus radial distance from the rotor's hub
  - PAXman integrated force versus radial distance from the rotor's hub

$$F_{PAXman} = \sum^{m} \frac{1}{2} \rho u_i^2 dA_i$$

Rotor Outwash
(Contours of radial velocity)



Animation of rotor outwash as extracted from the x-plane. Contours show velocity magnitude. Final freeze frame shows time-averaged radial rotor outwash velocity.



Paper: Silva, M., and Riser, R., "CH-47D Tandem Rotor Outwash Survey," Proceedings of the 67th Annual American Helicopter Society Forum., Virginia Beach, Virginia, 2011.

Overview

- Background
- Study Overview
- Results and Discussion
- Concluding Remarks

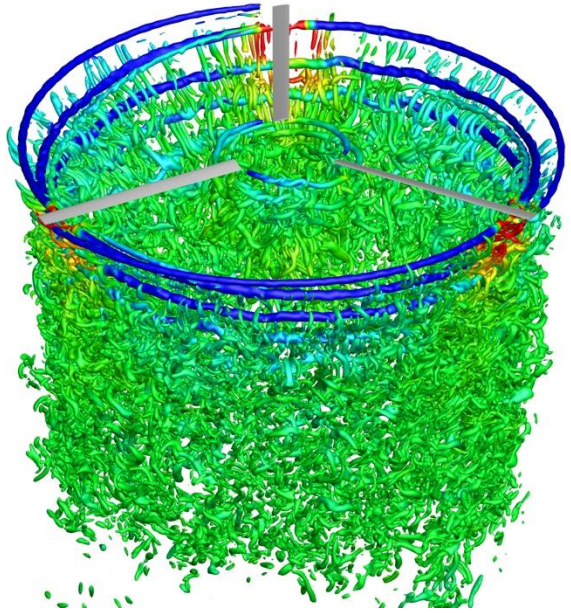
Overview

- **Background**
- **Study Overview**
- **Results and Discussion**
  - Single Rotor OGE
  - Single Rotor IGE
  - Tandem Rotor IGE
- **Concluding Remarks**

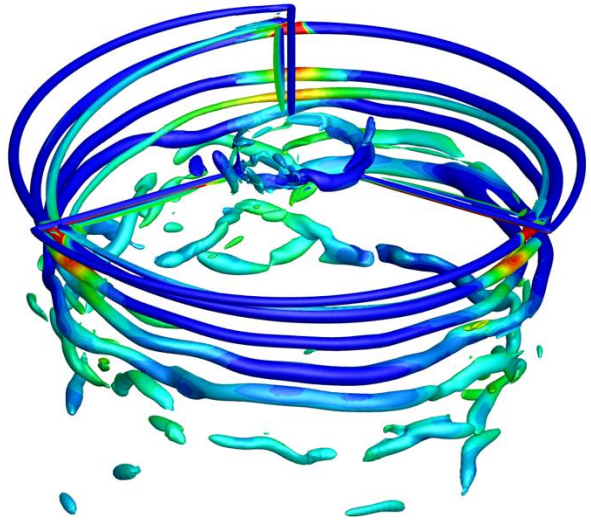
Single Rotor OGE

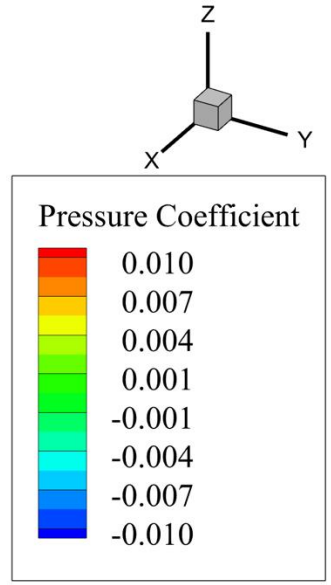
- **An isolated rotor is modeled hovering out of ground effect.**
- **Three-bladed rotors hovering IGE with tip Mach number of 0.61 and radius of 30 ft.**
  - Near-Body
    - 3rd order Central Differencing
    - Spalart-Allmaras with Rotation Corrections
  - Off-Body
    - 6th order Central Differencing
    - Laminar Flow

Blade-Resolved



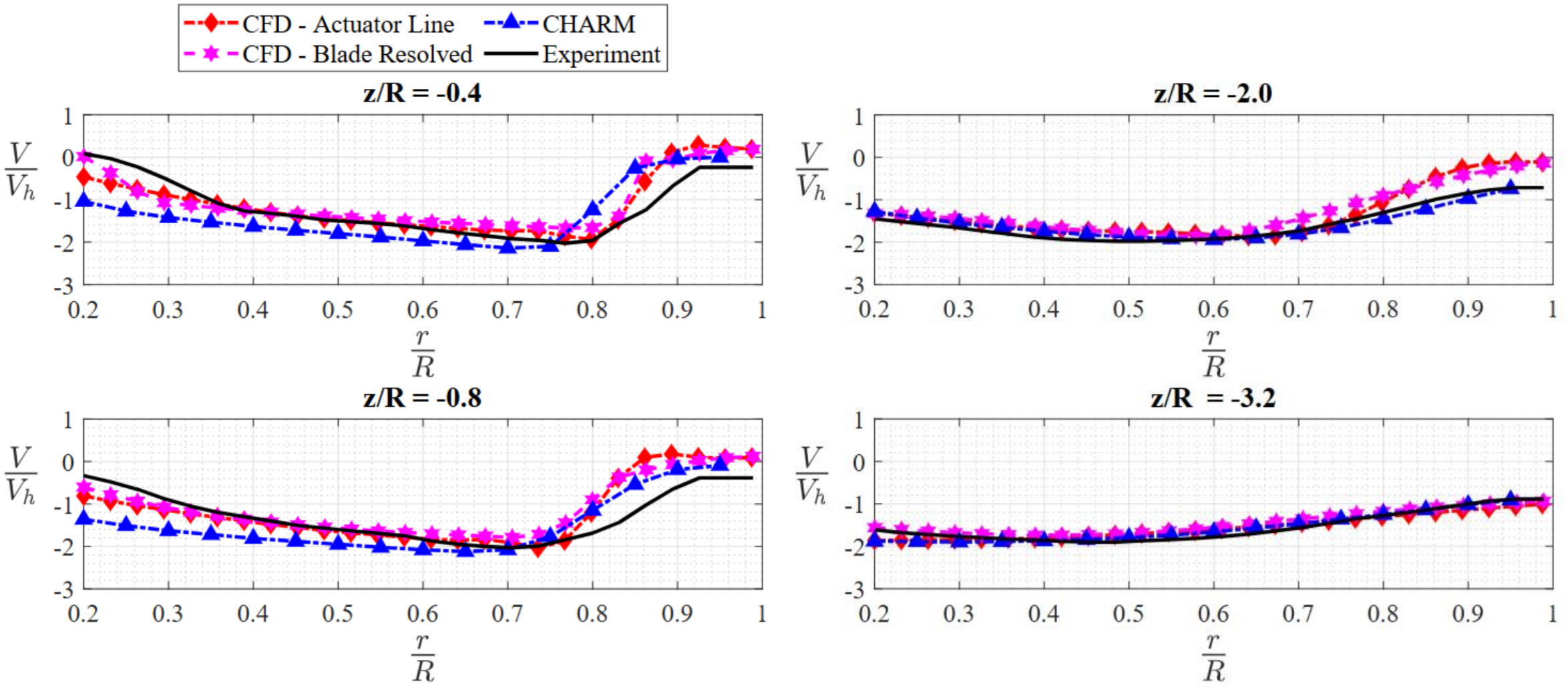
Actuator Line





Value	Blade-Resolved (40 revs)	Actuator Line (40 revs)	CHARM (600 revs)
CPUs	1,200	224	8
Hours	60	4	4
Core Hours	72,000	896	32

Single Rotor OGE – Results



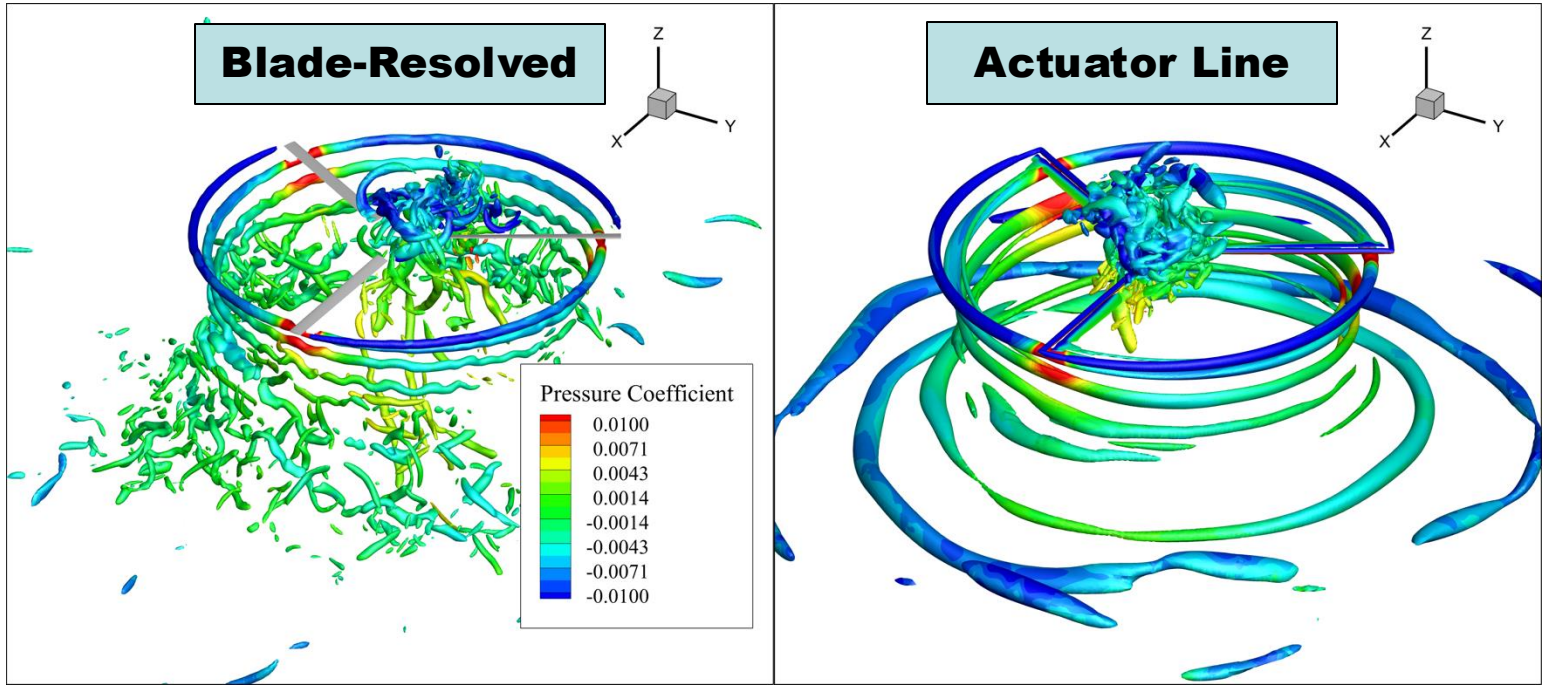
Overview

- **Background**
- **Study Overview**
- **Results and Discussion**
  - Single Rotor OGE
  - Single Rotor IGE
  - Tandem Rotor IGE
- **Concluding Remarks**

Single Rotor IGE

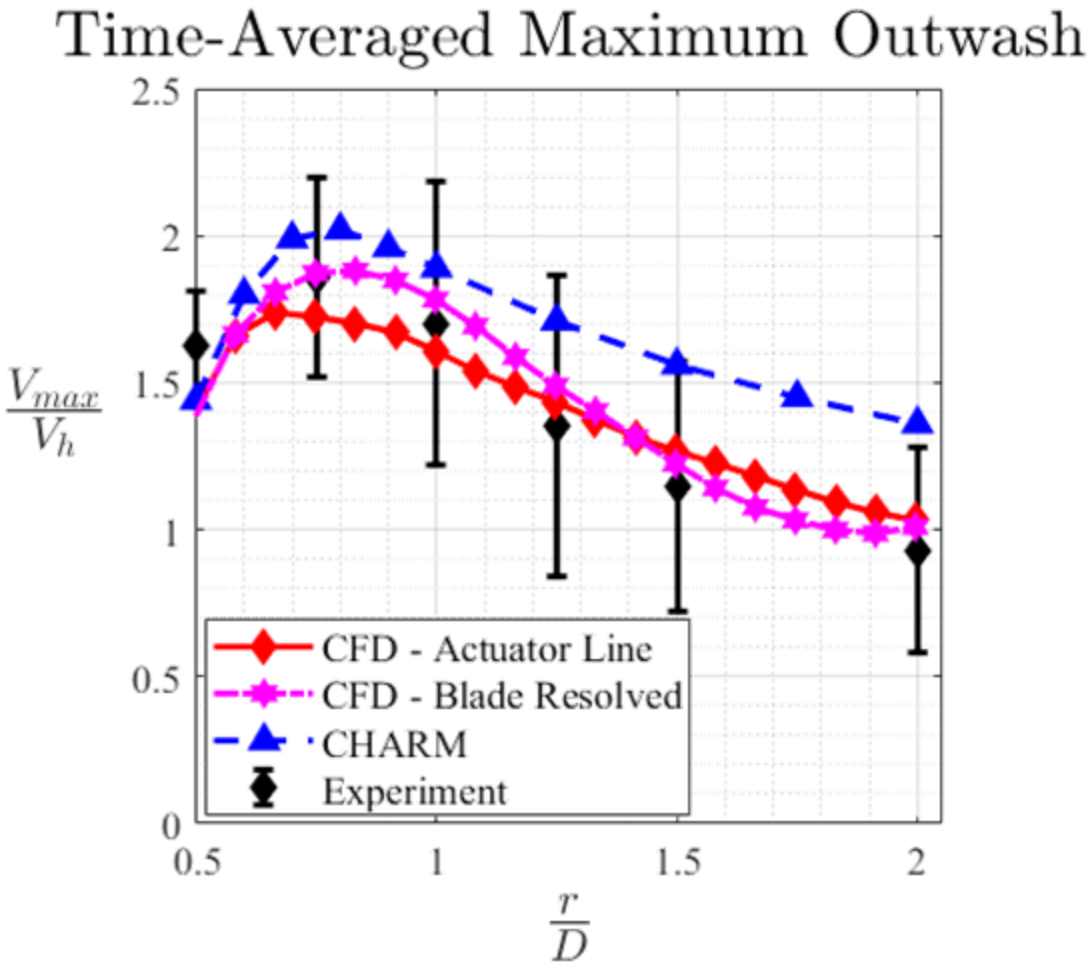
- **An isolated rotor is modeled hovering at a height of 0.571 diameter.**

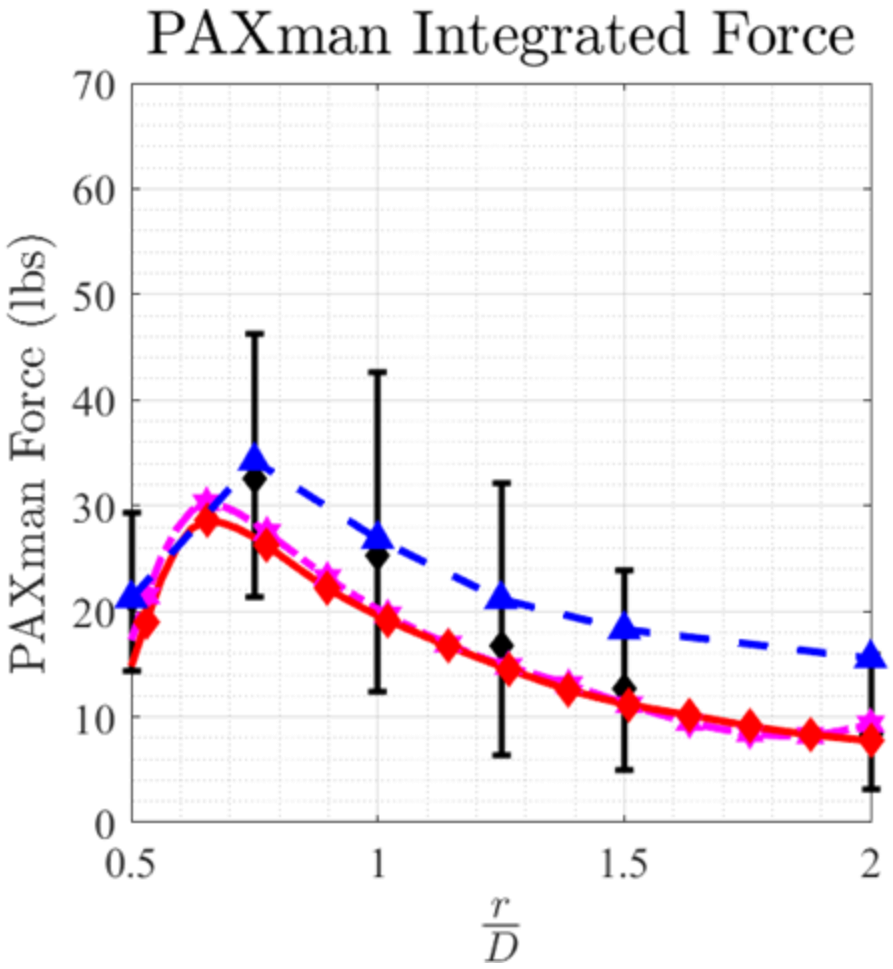
- **Three-bladed rotors hovering IGE with tip Mach number of 0.61 and radius of 30 ft.**
  - Near-Body
    - 3rd order Central Differencing
    - Spalart-Allmaras with Rotation Corrections
  - Off-Body
    - 6th order Central Differencing
    - Laminar Flow



Value	Blade-Resolved (40 revs)	Actuator Line (40 revs)	CHARM (600 revs)
CPUs	1,440	336	8
Hours	140	12	5
Core Hours	201,600	4,032	40

Single Rotor Configuration – IGE





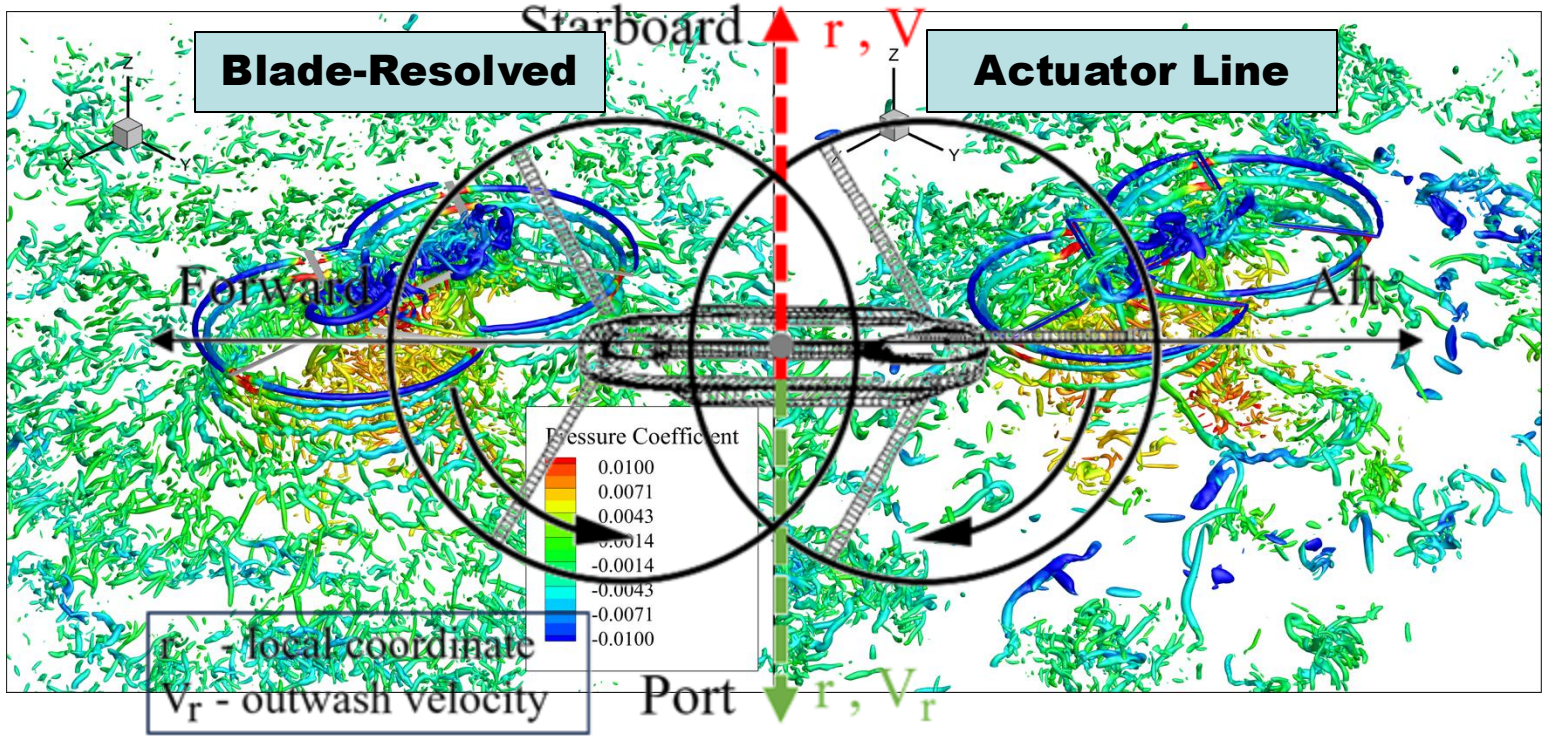
Overview

- **Background**
- **Study Overview**
- **Results and Discussion**
  - Single Rotor OGE
  - Single Rotor IGE
  - Tandem Rotor IGE
- **Concluding Remarks**

Tandem Rotor IGE

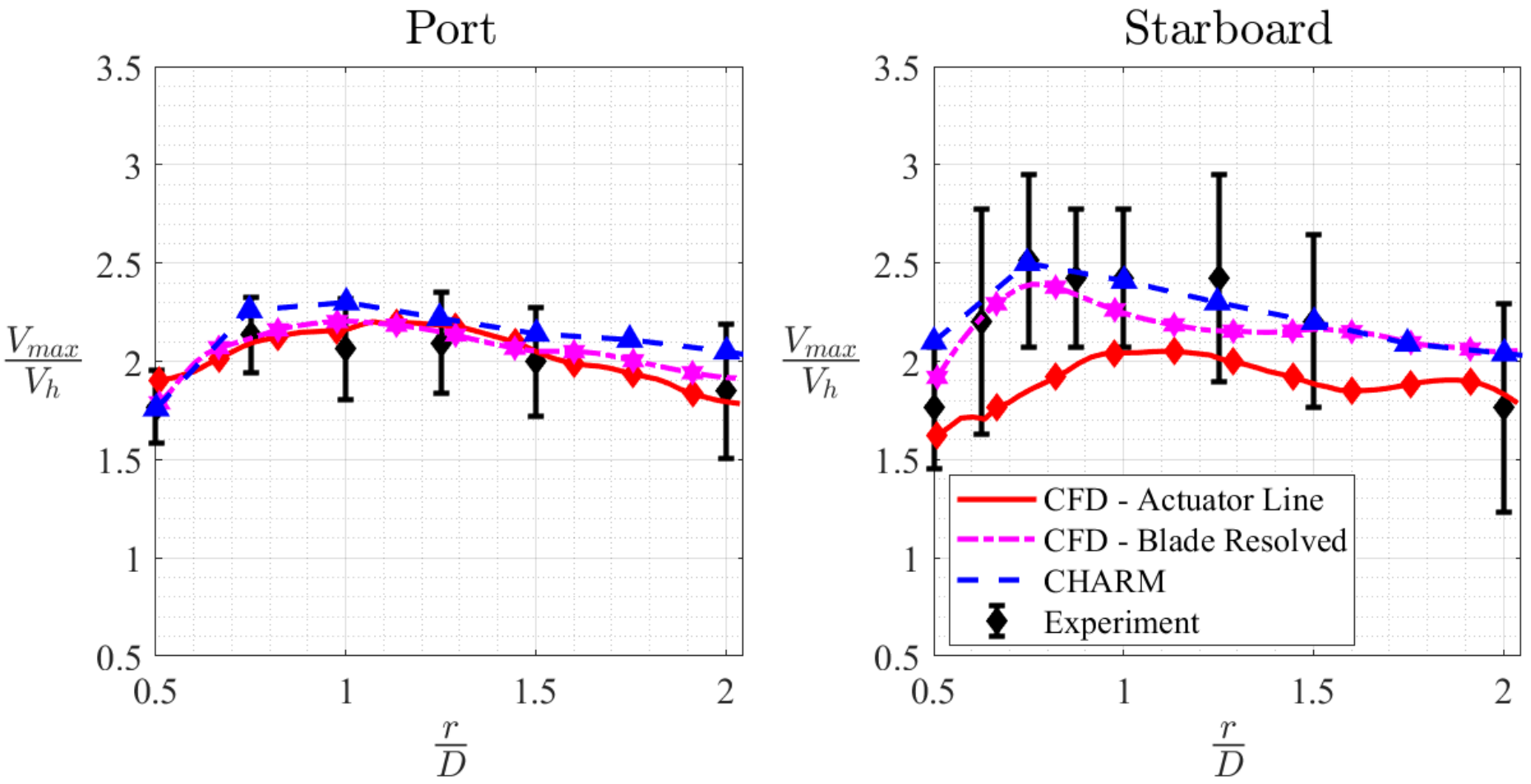
- **A tandem rotor configuration is modeled hovering at a height of 0.571 diameter.**

- **Two three-bladed rotors hovering IGE with tip Mach number of 0.61 and radius of 30 ft.**
  - Near-Body
    - 3rd order Central Differencing
    - Spalart-Allmaras with Rotation Corrections
  - Off-Body
    - 6th order Central Differencing
    - Laminar Flow

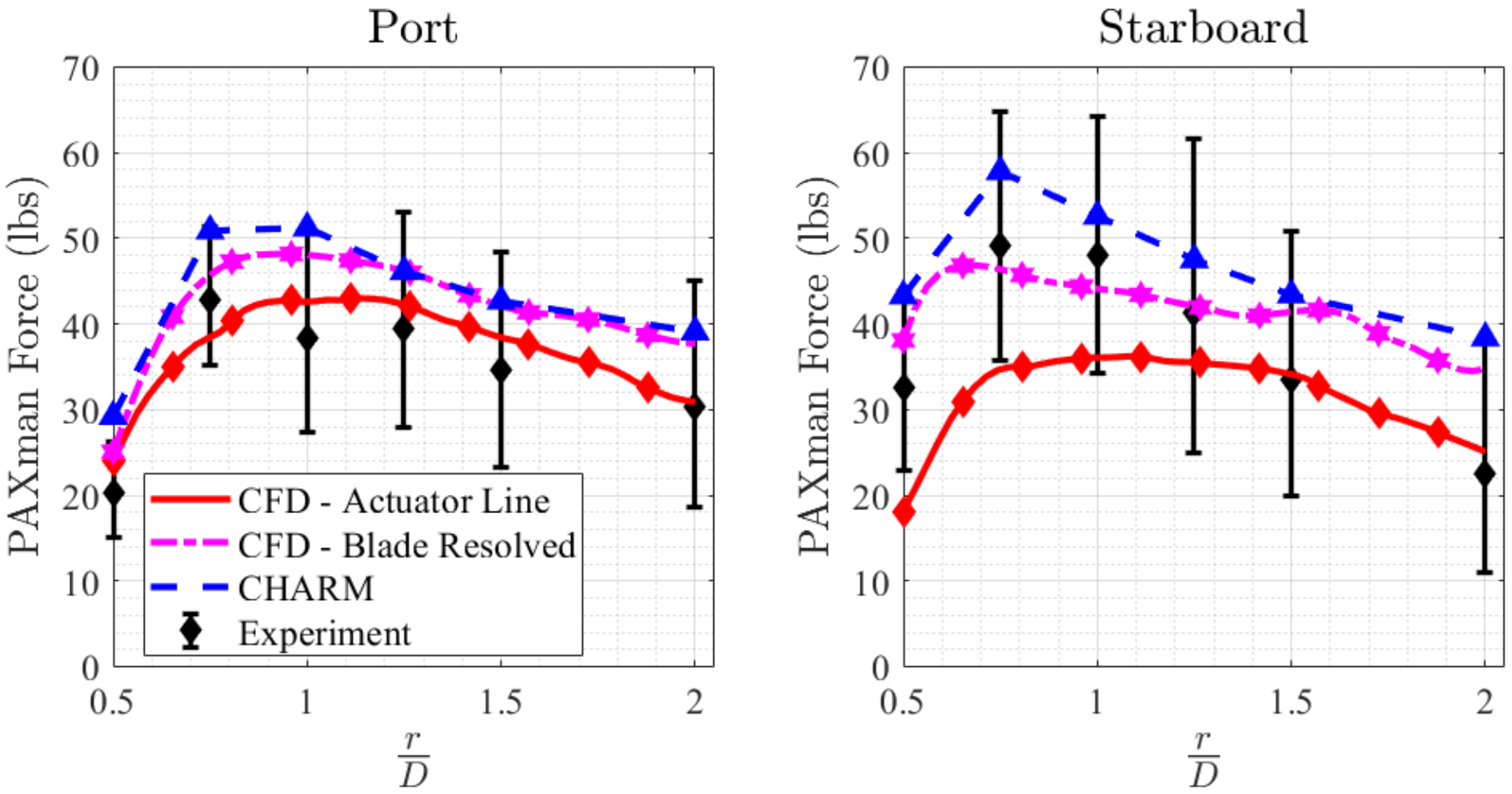


Value	Blade Resolved (40 revs)	Actuator Line (40 revs)	CHARM (600 revs)
CPUs	1,440	336	8
Hours	240	30	15
Core Hours	345,600	10,080	120

Tandem Rotor IGE – Time-Averaged Maximum Outwash



Tandem Rotor IGE – PAXman Integrated Force

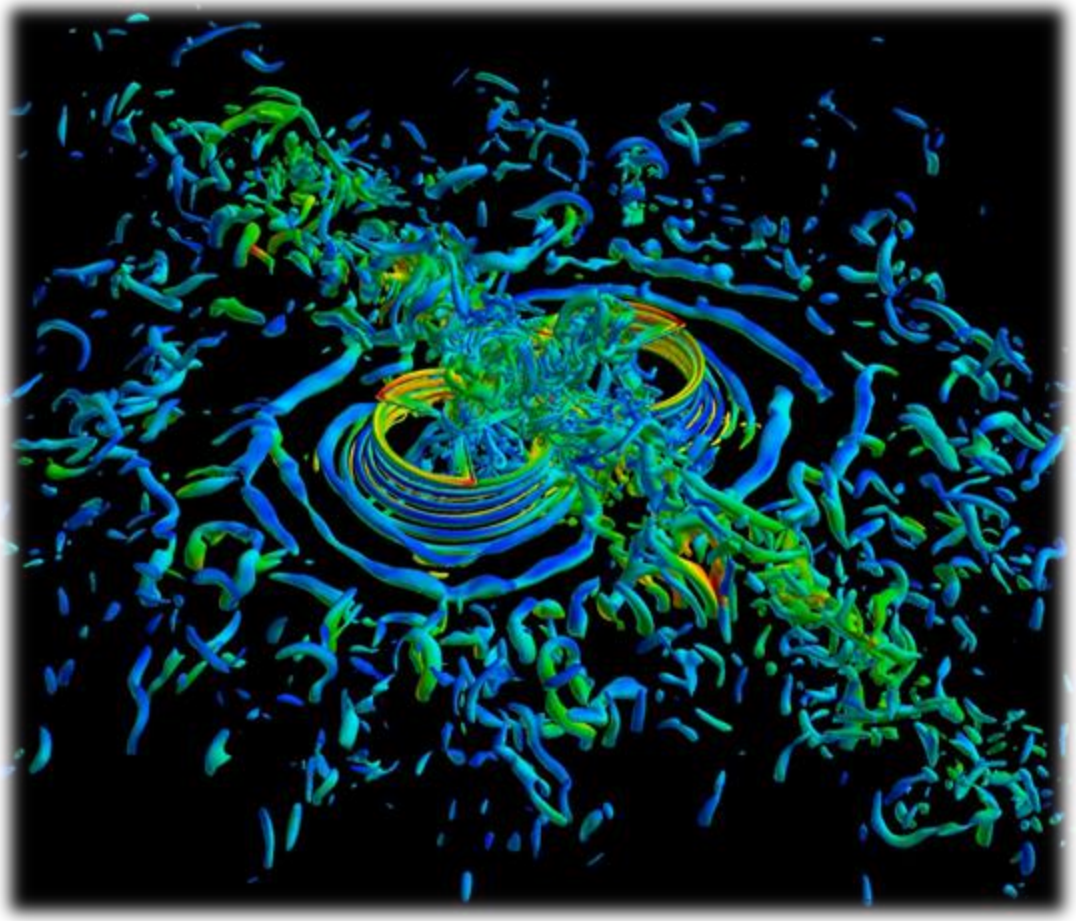


Overview

- Background
- Study Overview
- Results and Discussion
- Concluding Remarks

Concluding Remarks

- **This effort was successful in achieving its primary research objective.**
  - A preliminary actuator line model was implemented within the OVERFLOW CFD code
- **The actuator line model achieved reasonable outwash predictions at a greatly reduced computational expense compared to blade-resolved CFD.**
- **For the metrics and configuration investigated in this study, the CHARM model provides a superior balance between modeling fidelity and computational cost.**
- **The current actuator line model implemented in this study is still a NASA internal module for the OVERFLOW CFD code.**



Subsequent Work Following SciTech 2025

- **Supporting pre-test predictions for future tandem rotor outwash experiments within RVLT.**
  - Sweeping rotor-rotor spacing, rotor-rotor high difference, rotor-rotor thrust difference, ect.



- **Expanding validation effort to encompass more diverse use cases of rotorcraft CFD simulation.**
  - Hovering
  - Forward flight
  - Downwash/Downloading



Acknowledgements

- RVLT management for funding support in this effort
- NASA Ames Aeromechanics Office for help in understanding the outwash problem
- OVERFLOW development team for their assistance/support

