

Outwash Test Results for a Single Rotor in Hover

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VFS 82nd Annual Forum and Technology Display
West Palm Beach, FL
May 7, 2026



Overview

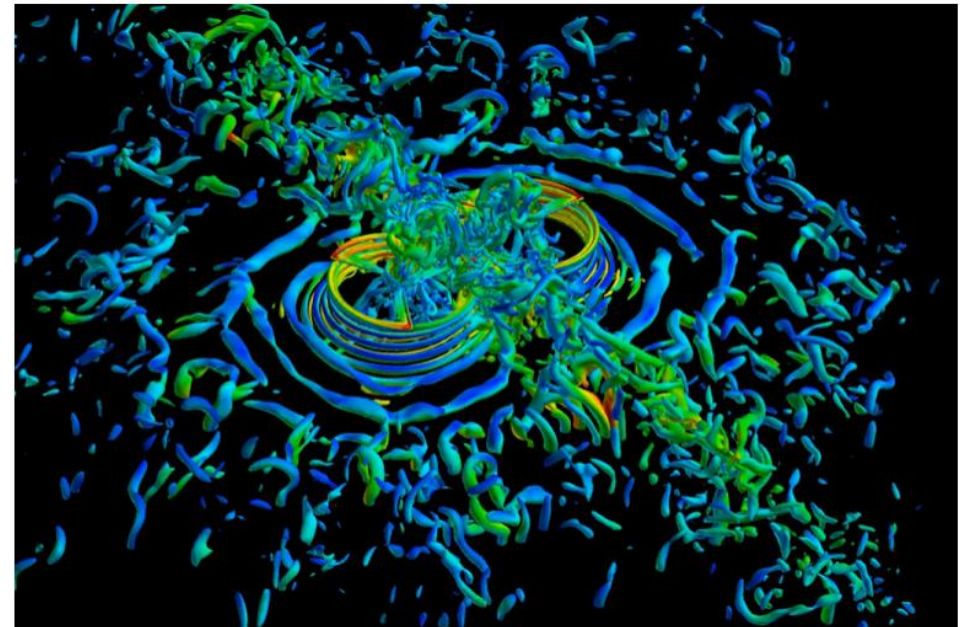
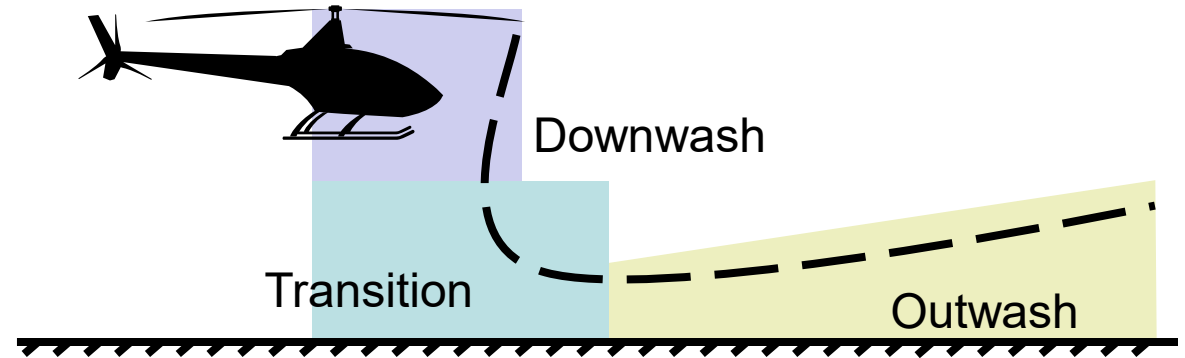


- Introduction
- Rotor and Instrumentation
- Test Conditions and Procedure
- Sample Results
- Summary
- Future Work



Introduction

- Outwash results when rotor downwash interacts with a ground plane
- Historically of interest to armed forces
 - Risk of damage to personnel and equipment
 - Contributes to degraded visual environment
- Recent eVTOL industry and government regulatory interest
 - Safety of civilian passengers and crew
 - Novel vertiport environment
- Challenges
 - High disk loading
 - Incomplete understanding of multirotor interactions



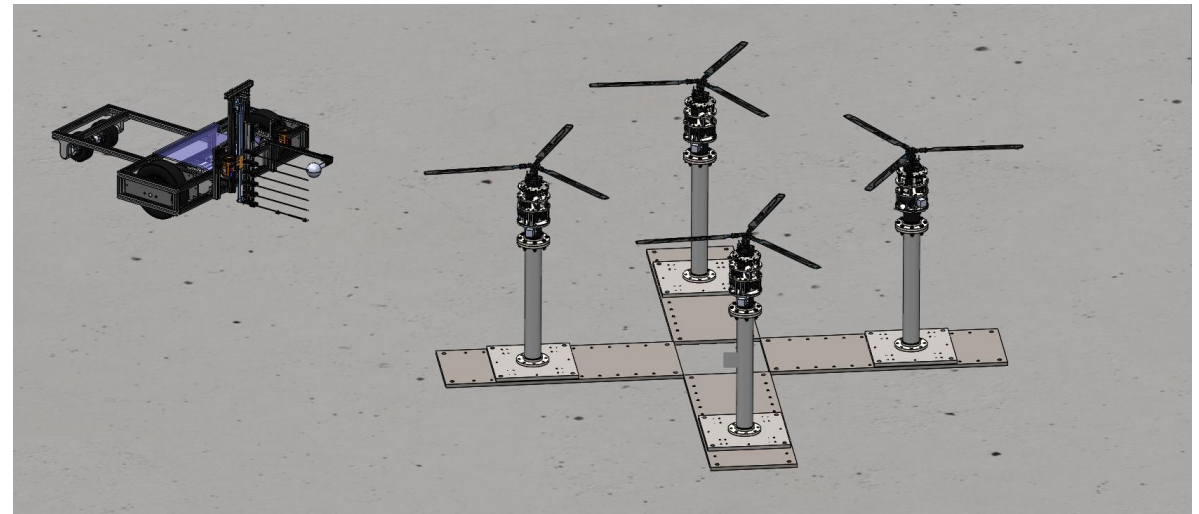
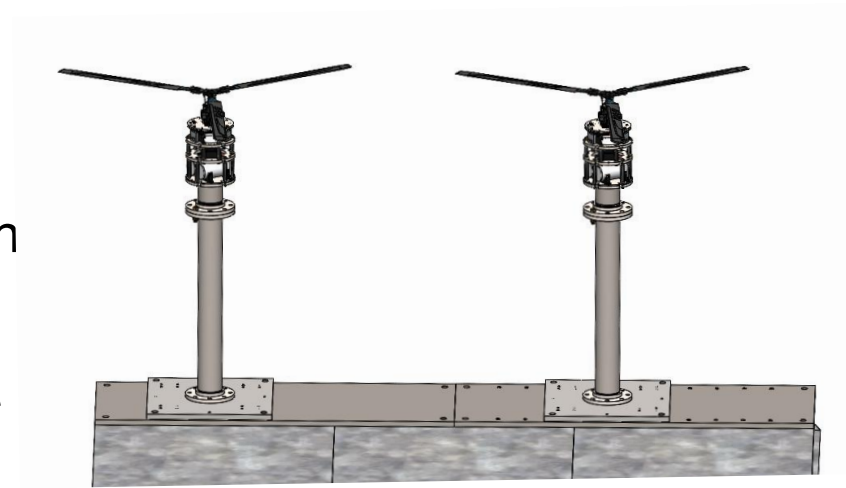


Gather high spatial-resolution outwash velocity measurements on single and multi-rotor configurations for tool validation

Approach



- Phase 1—Single Rotor
 - Develop hardware and measurement technique
- Phase 2—Dual Rotor
 - Examine the effects of interacting rotor wakes on outwash
- Phase 3—Quad Rotor
 - Explore outwash characteristics unique to eVTOL aircraft



Outwash Rotor



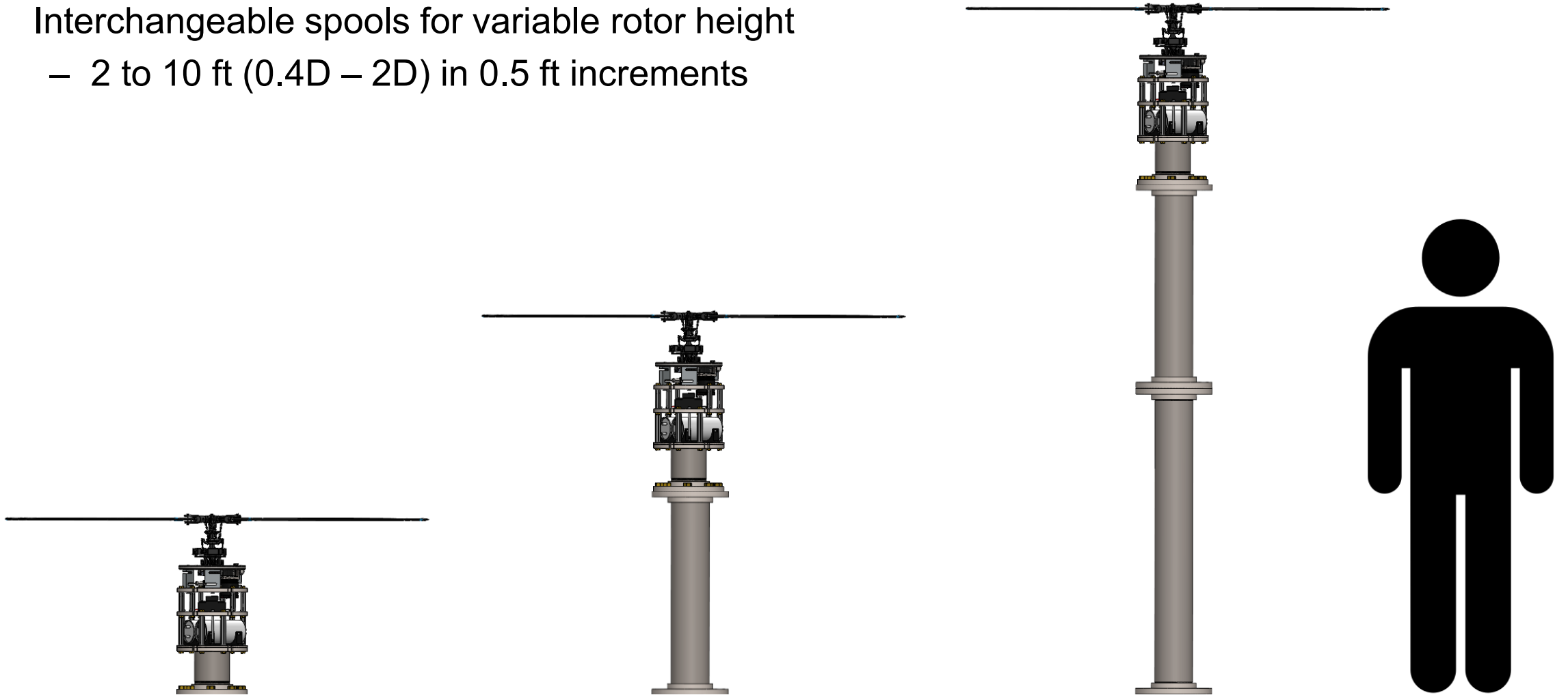
- Rotor, hub, swashplate, transmission, motor all from SAB Goblin 700S R/C Helicopter
- Rotor
 - 5 ft diameter, 3-blade, $\sigma=0.0755$
 - Untwisted blades, symmetric airfoil, ~12% t/c
 - Easily modified for reverse rotation
 - 2000 RPM maximum with closed loop control
- Swashplate for remote collective and cyclic control
- 3x uniaxial loadcells for thrust and moment measurement
- Performance
 - 40 lb thrust at 1600 RPM



Rotor Stand

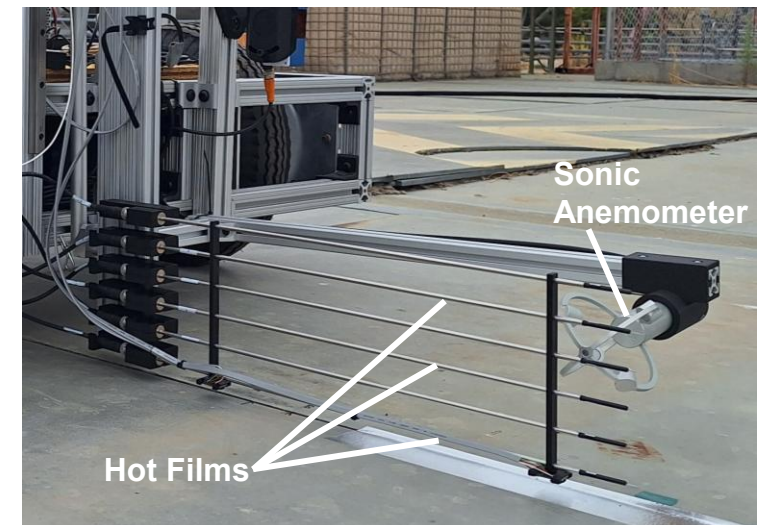
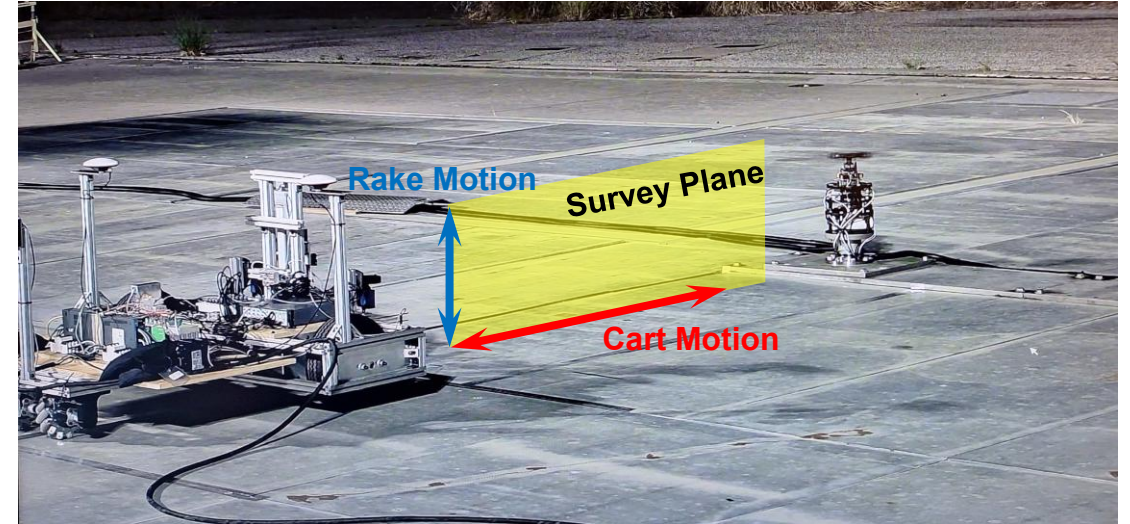


- Interchangeable spools for variable rotor height
 - 2 to 10 ft (0.4D – 2D) in 0.5 ft increments



Instrumentation Cart

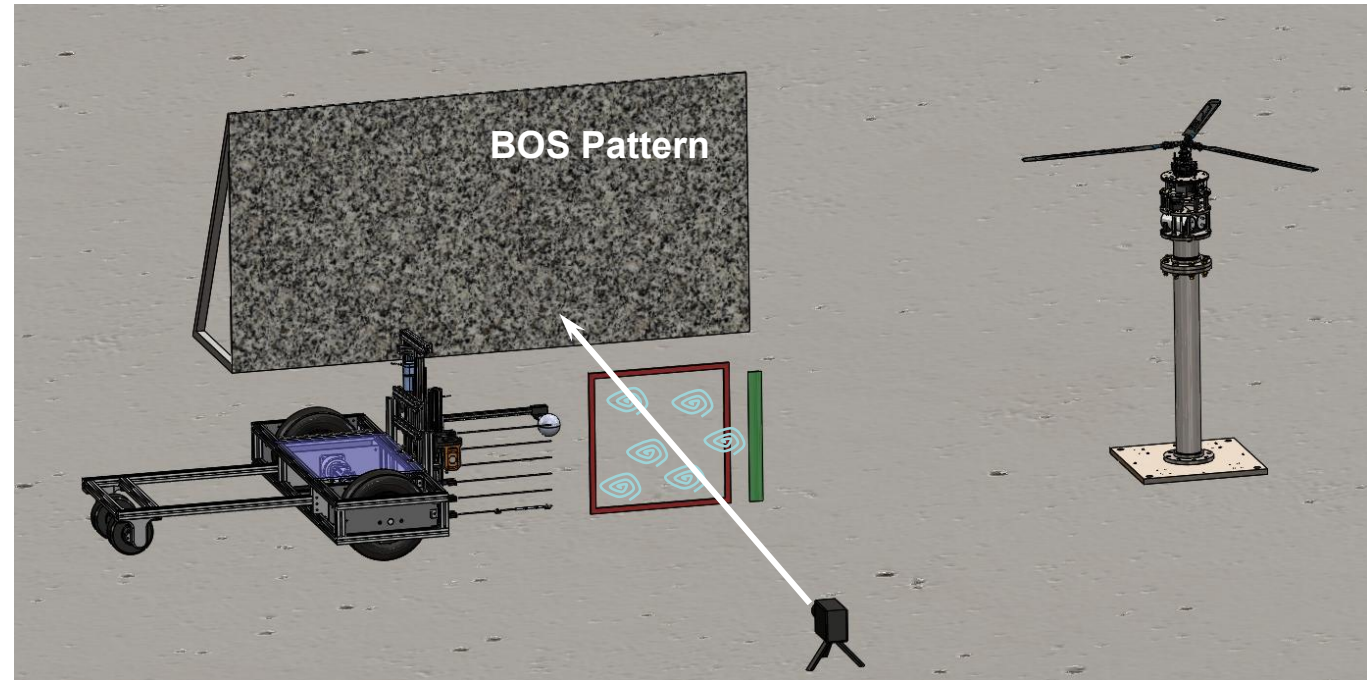
- Semi-autonomous linear travel
 - GPS position and direction within 0.25-in / 1°
- Vertical traversing rake
 - 6x single-wire hot films on 18-in probe supports
 - 1x TriSonica Sphere sonic anemometer
- Data acquisition system
 - Dantec 6-channel CTA, 10 kHz bandwidth
 - WiFi telemetry and control



Schlieren Velocimetry



- New measurement technique developed in collaboration with DLR
- Helium is seeded into rotor outwash upstream of cart
- Camera captures Background Oriented Schlieren (BOS) pattern viewed through seeded flow
- Density gradient in seeded flow produces optical displacement of BOS background features
- Post-processing software tracks density changes between consecutive frames to deduce velocity



Test Conditions

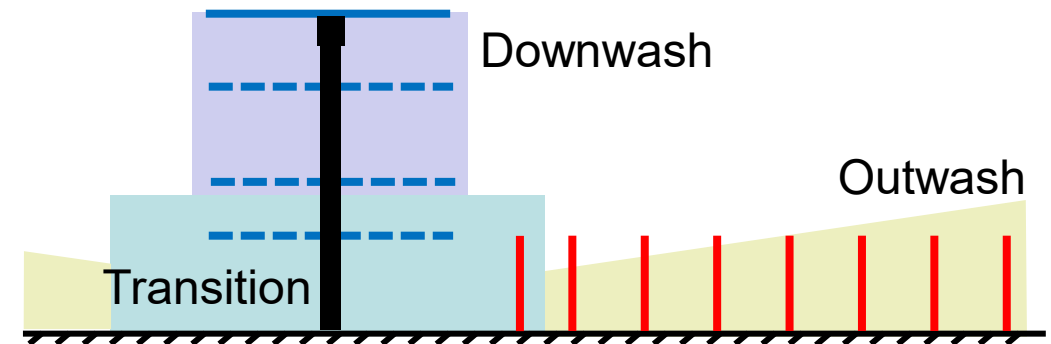
- The test was conducted at the Outdoor Aerodynamic Research Facility (OARF) at NASA Ames Research Center
- Stand and Cart

Parameter	Value
Stand Heights	0.4, 0.6, 1.0, 1.4 D
Cart Positions	0.6–4.0 D
Hot Film Positions	0.5–13.63 in (0.63 in increment)

- Rotor Trim

Parameter	Value
Rotor Speed	1200, 1600
C_T/σ	0.03, 0.05, 0.06, 0.09
Moment ^a	0, 40, 80 in-lb
Local Wind Speed	<2 ft/s

^a Measurement has been performed at the plane of 0, 45, 90 degrees



Sample Results

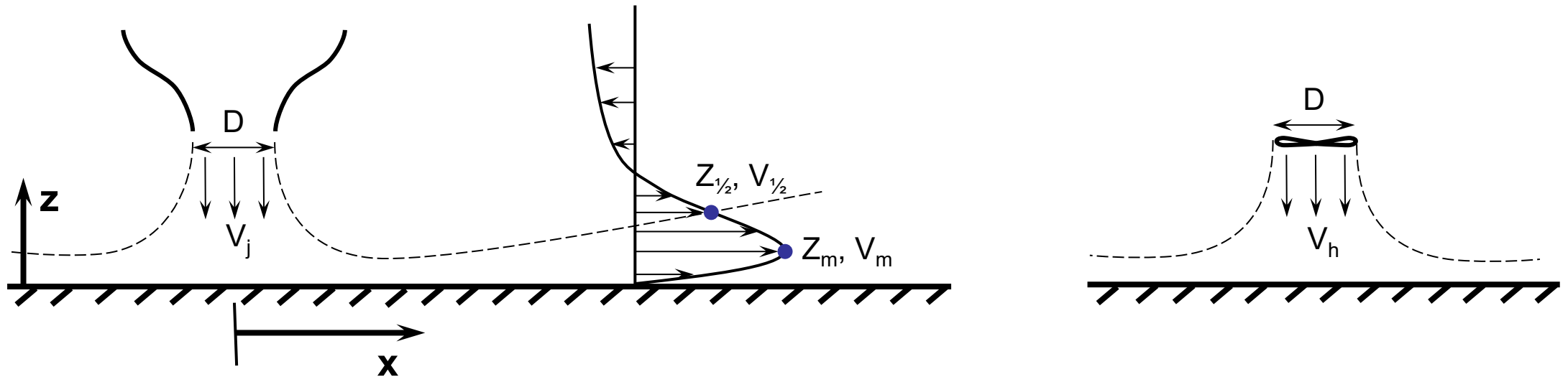


- Wall Jets
- Rotor height
- Cart distance
- Rotor thrust
- Hub moment
- Propagation Characteristics
- Schlieren Velocimetry



The Wall Jet Analogy

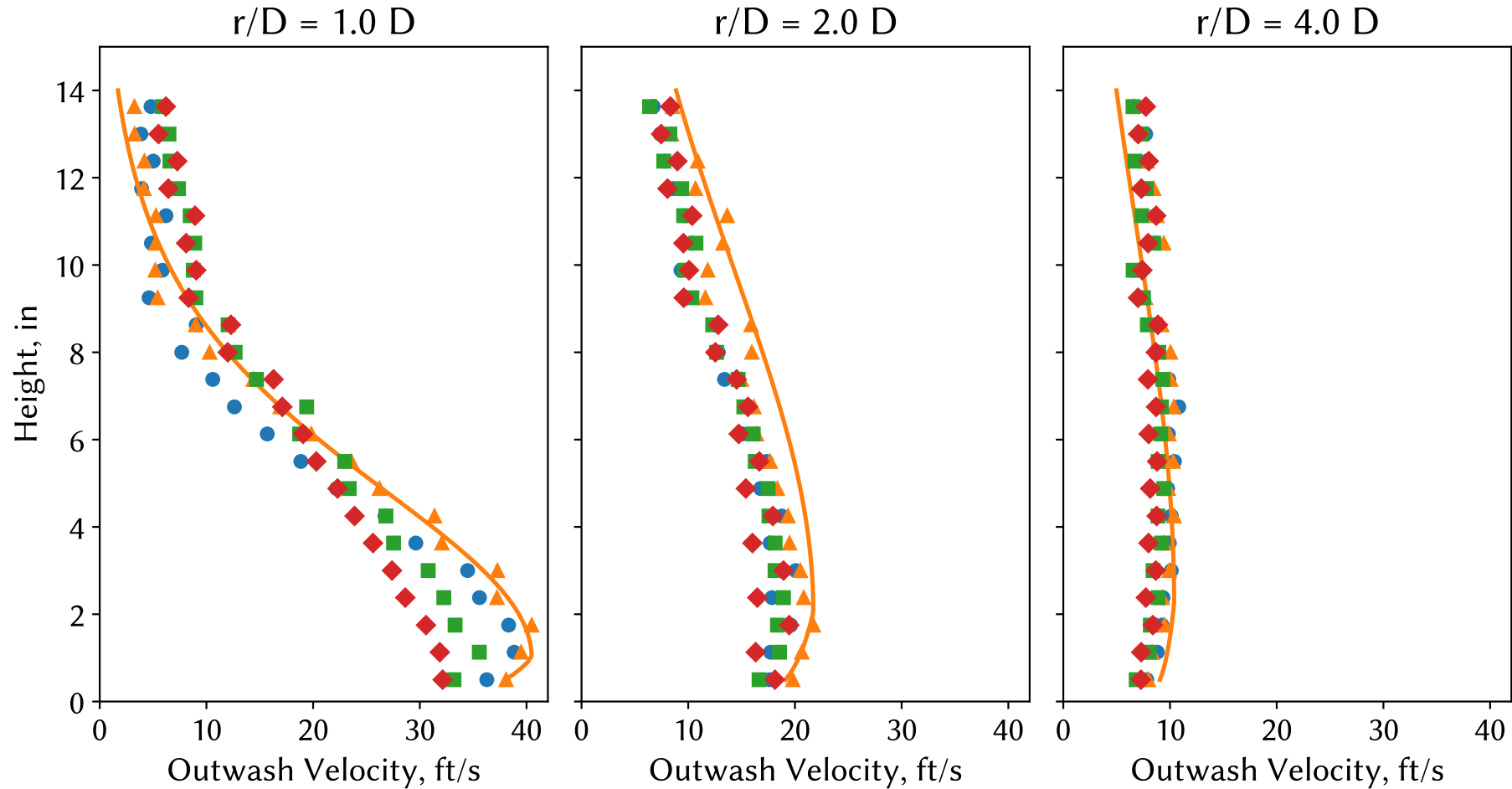
- M.B. Glauert (1956) characterized the flow along the wall using:
 - Maximum radial velocity, V_m
 - Wall jet half-height, $Z_{1/2}$
- Established $V_m \propto x^{-1/2}$ and $Z_{1/2} \propto x^{3/4}$
- Single rotor outwash is reminiscent of normal, axisymmetric wall jet flow



Effects of Rotor Height and Cart Distance



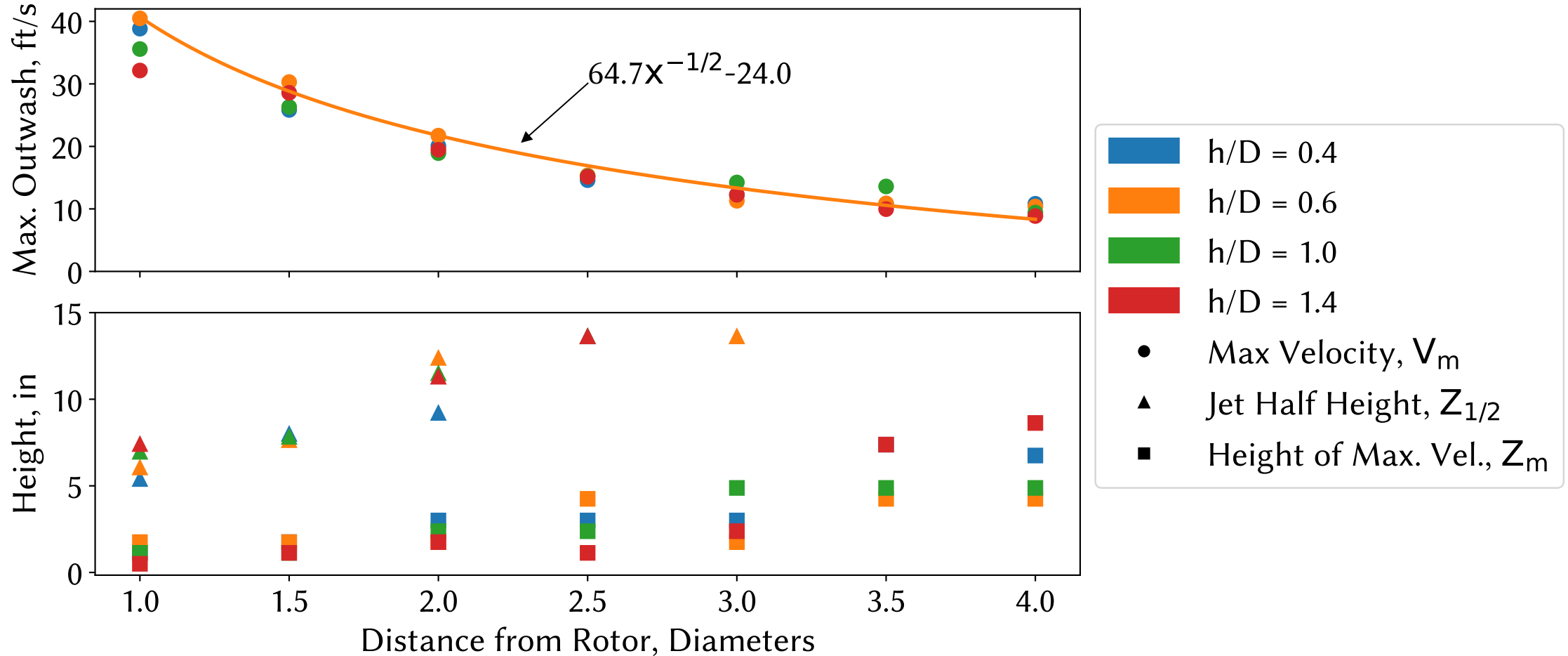
$CT/\sigma = 0.06$, Zero moment
 $r/D = 2.0 D$



Measured Wall Jet Parameters



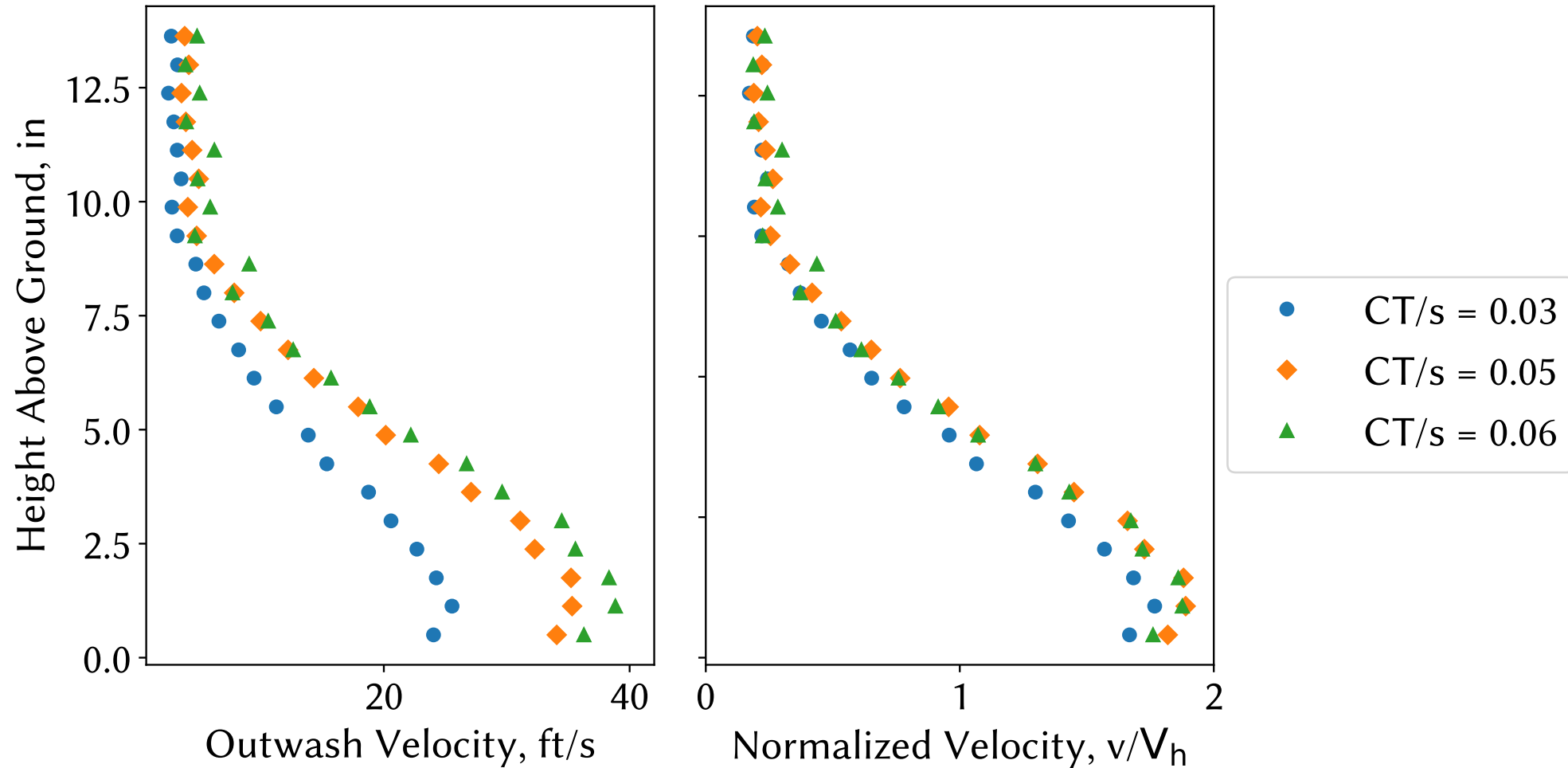
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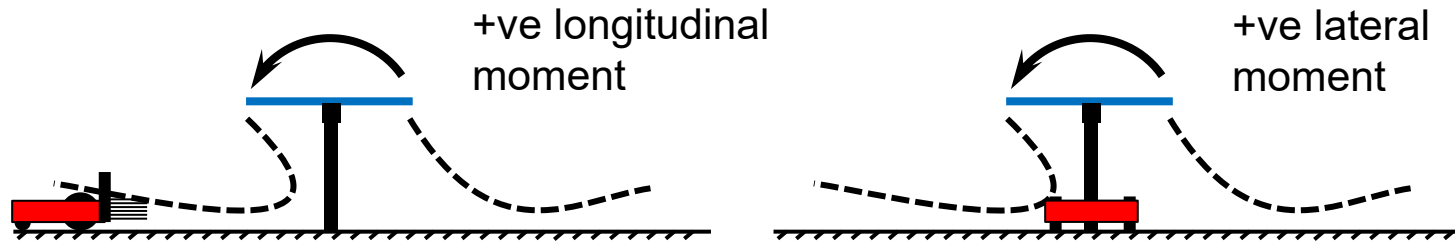
Thrust Effects on Outwash



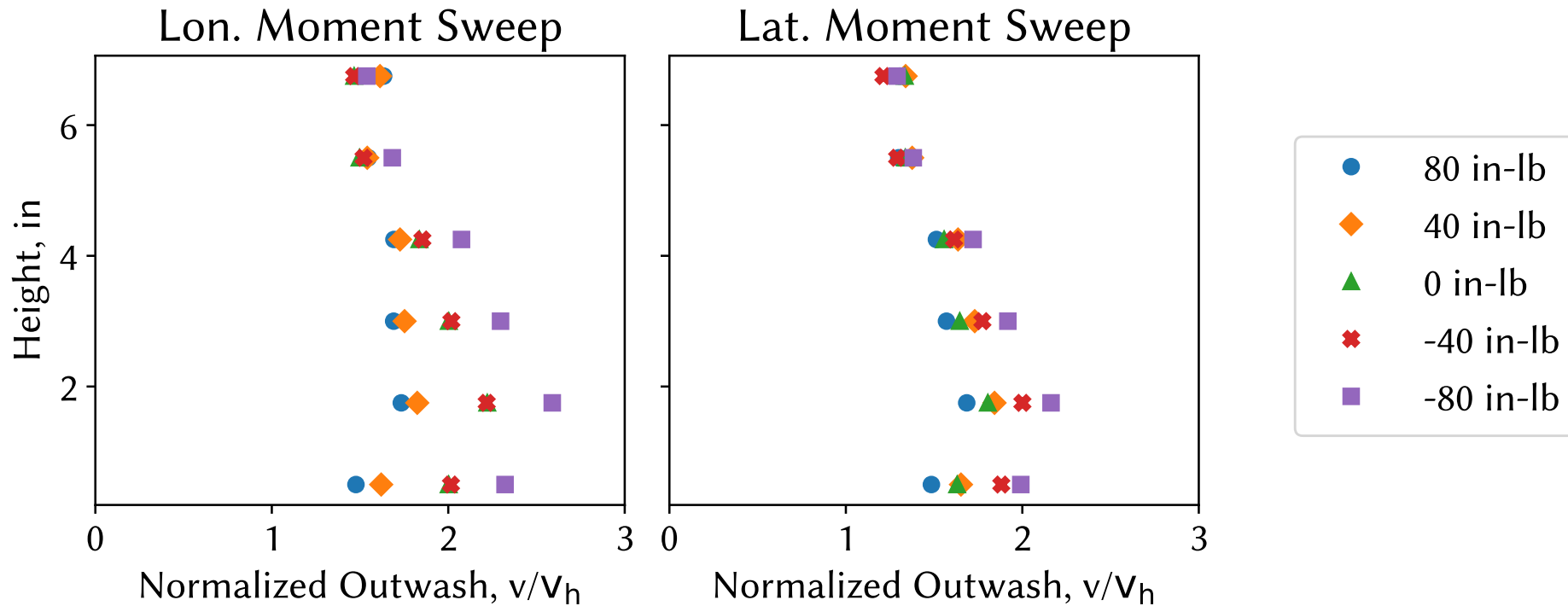
$h/D = 0.4$, $r/D = 1.0$, 1600 RPM, No Moments



Moment Effects on Outwash



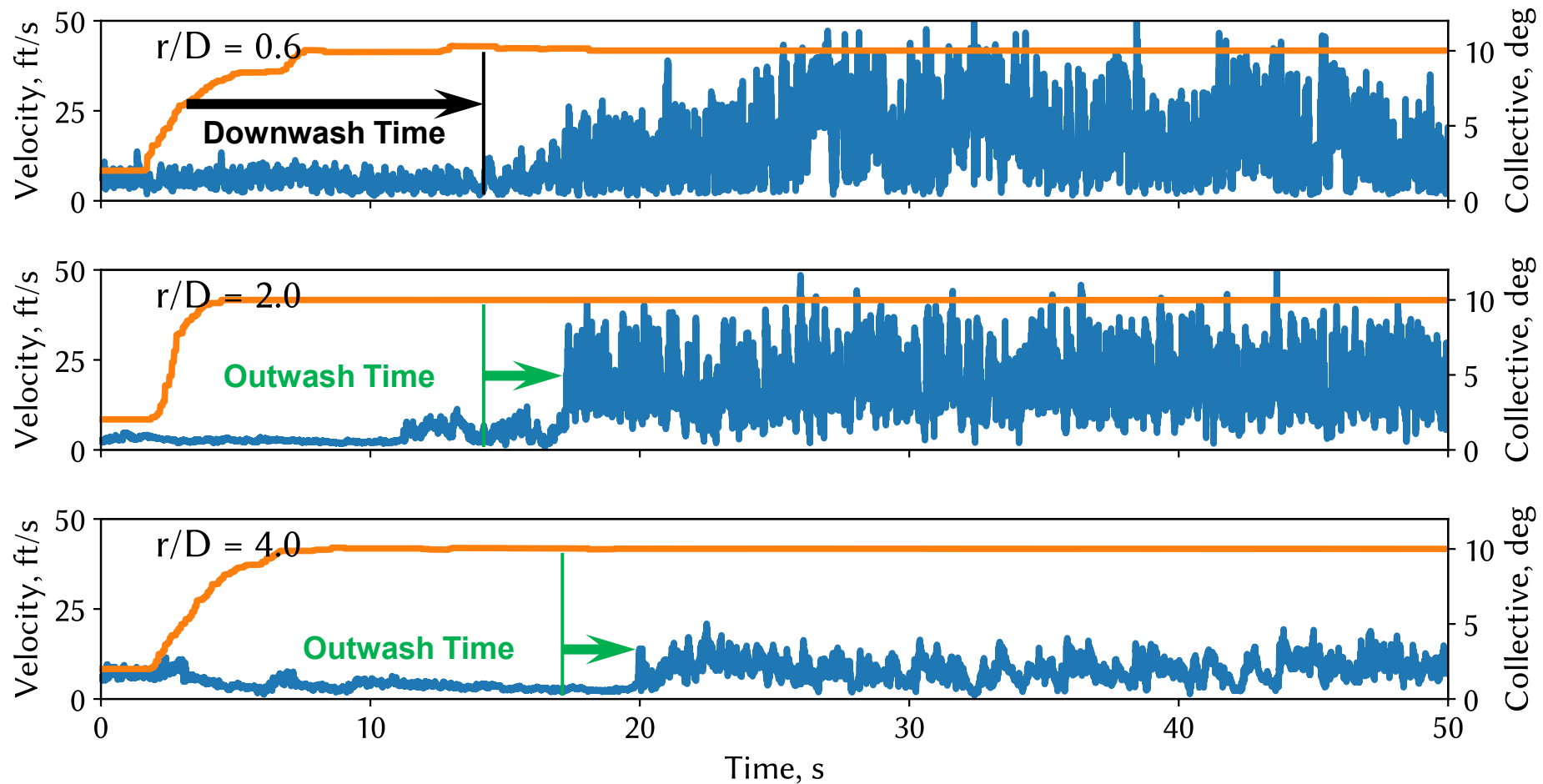
$h/D = 1.0, r/D = 1.5, T = 40 \text{ lb.}$



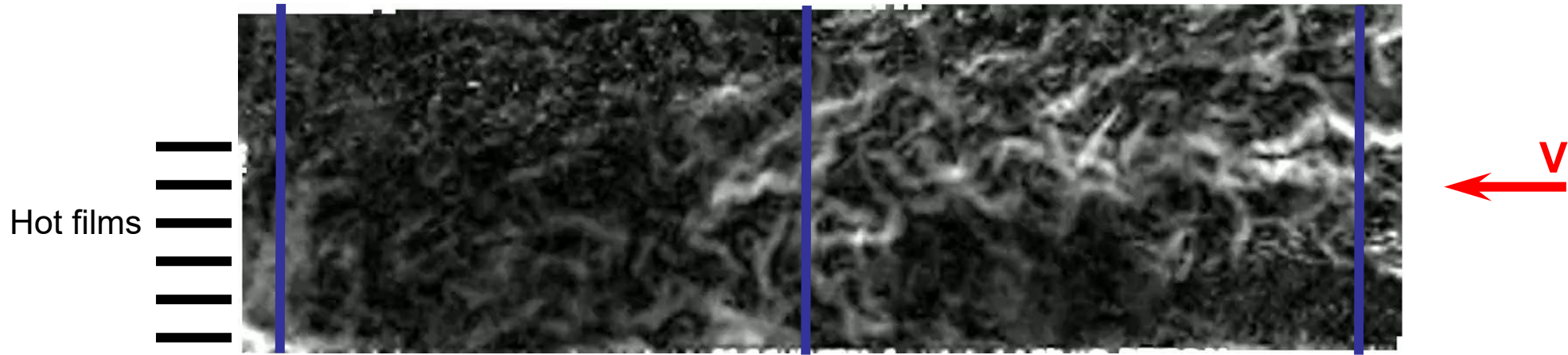


Outwash Propagation Characteristics

$$h/D = 1.0, C_T/\sigma \sim 0.02 \rightarrow 0.09, V_h \sim 9 \rightarrow 18 \text{ ft/s}$$



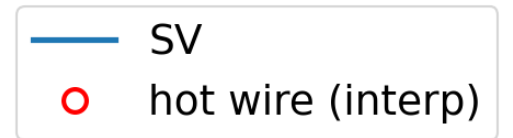
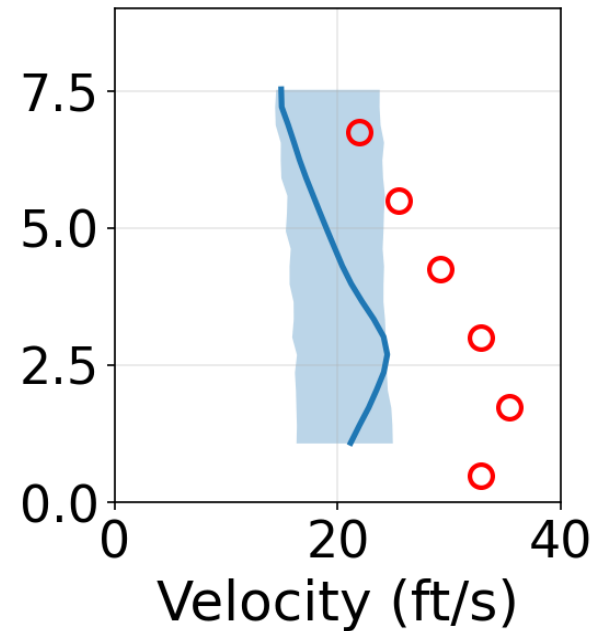
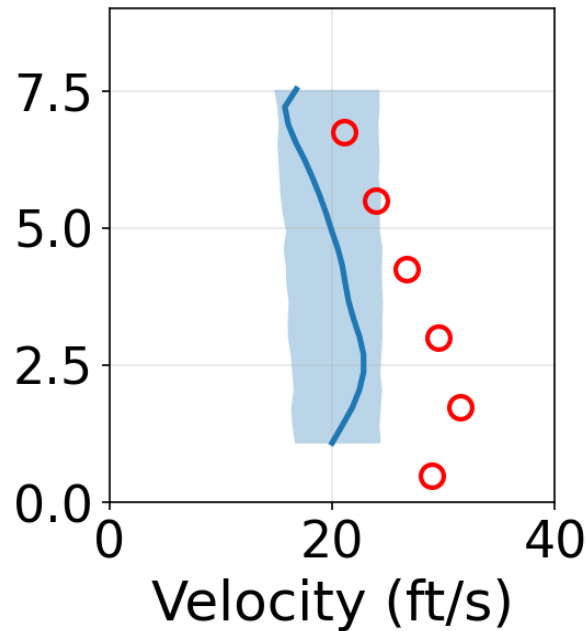
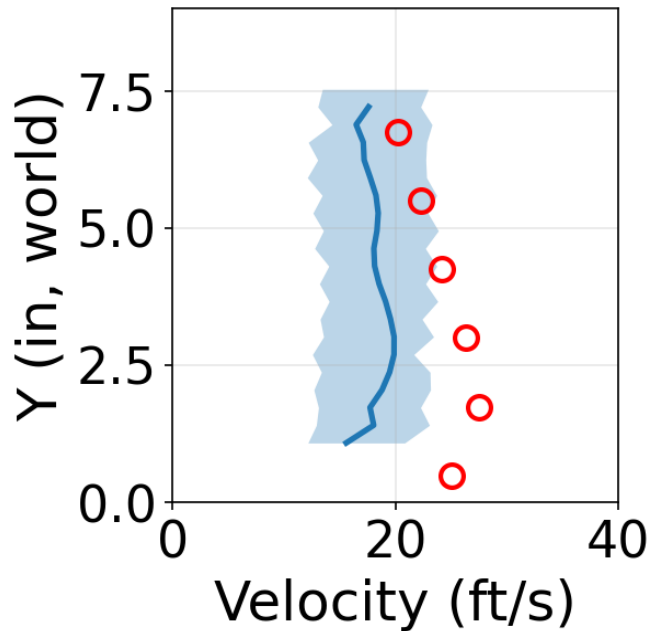
Schlieren Velocimetry



$r/D=2.0$

$r/D=1.8$

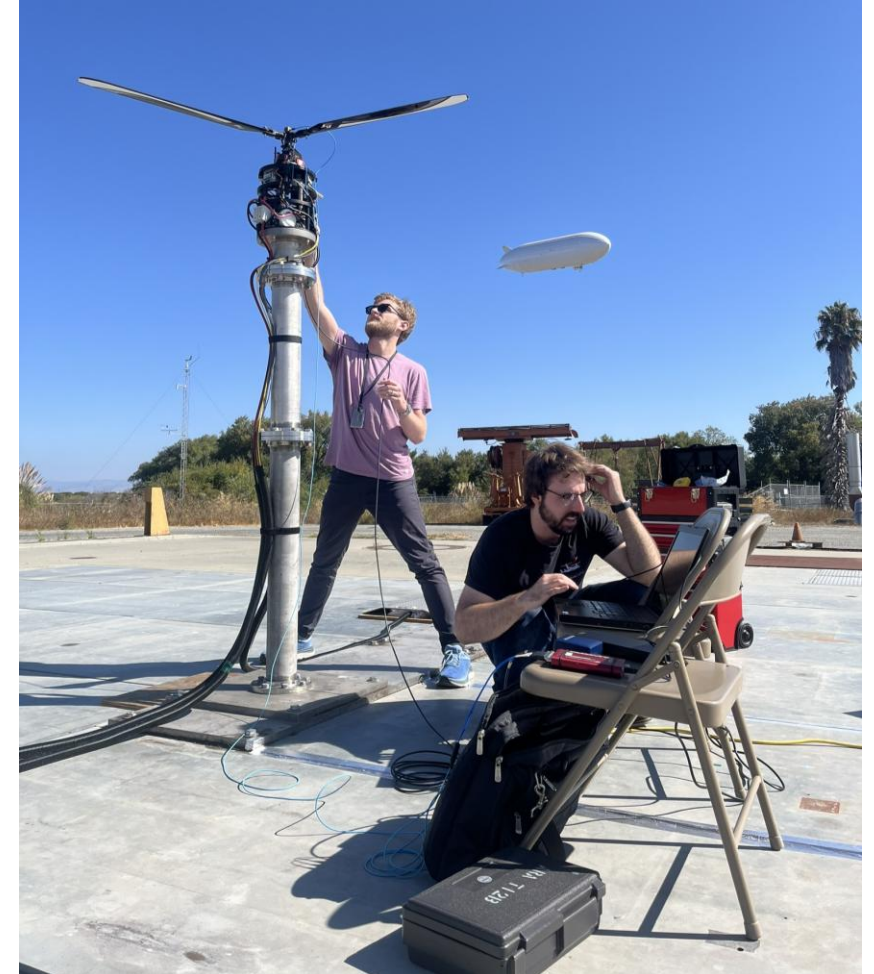
$r/D=1.6$



Summary

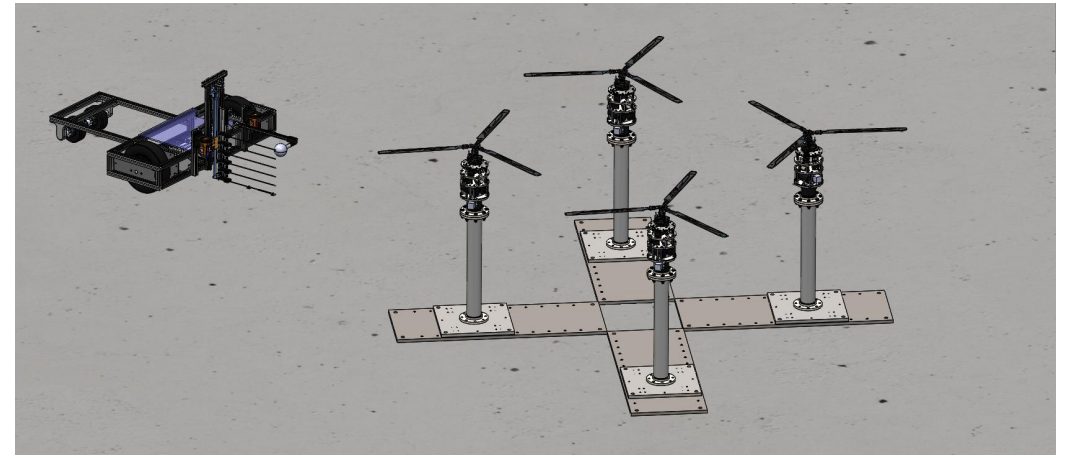
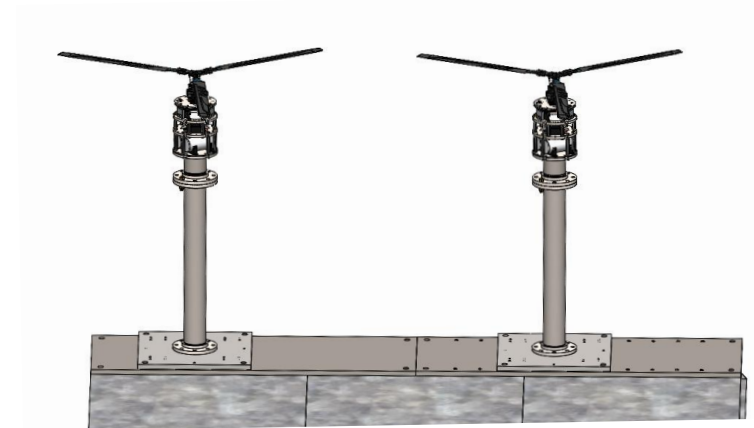


- Completed outwash measurements for a single rotor in hover
- Increasing rotor height provides modest relief of outwash velocity
- The wall jet is a useful model for outwash characteristics at a distance from the rotor
- Hover induced velocity is an effective predictor of peak outwash velocity
 - Peak outwash velocity near the rotor will approach $2V_h$
- Rotor trim significantly changes outwash velocity
- Downwash propagation time is much longer than outwash propagation time

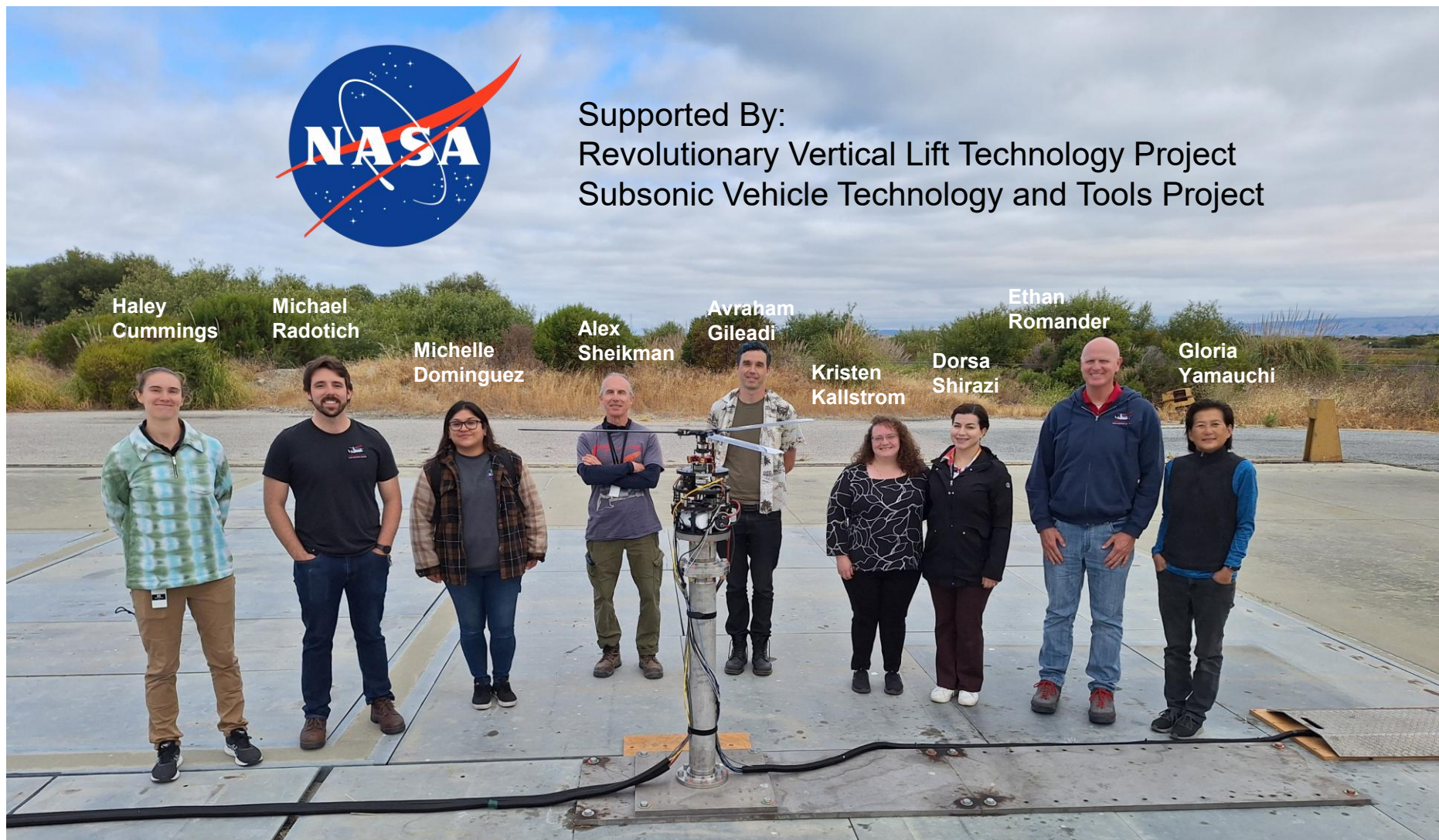
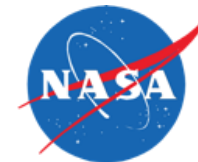


Future Work and Ideas

- Phase 1—Single Rotor
 - Publish data as a NASA Technical Report
- Phase 2—Dual Rotor
 - Examine the effects of interacting rotor wakes on outwash - 2026
- Phase 3—Quad Rotor
 - Explore outwash characteristics unique to eVTOL aircraft
- Additional Ideas
 - Wing and fuselage effects
 - Vertiport interactions
 - External collaboration



Questions



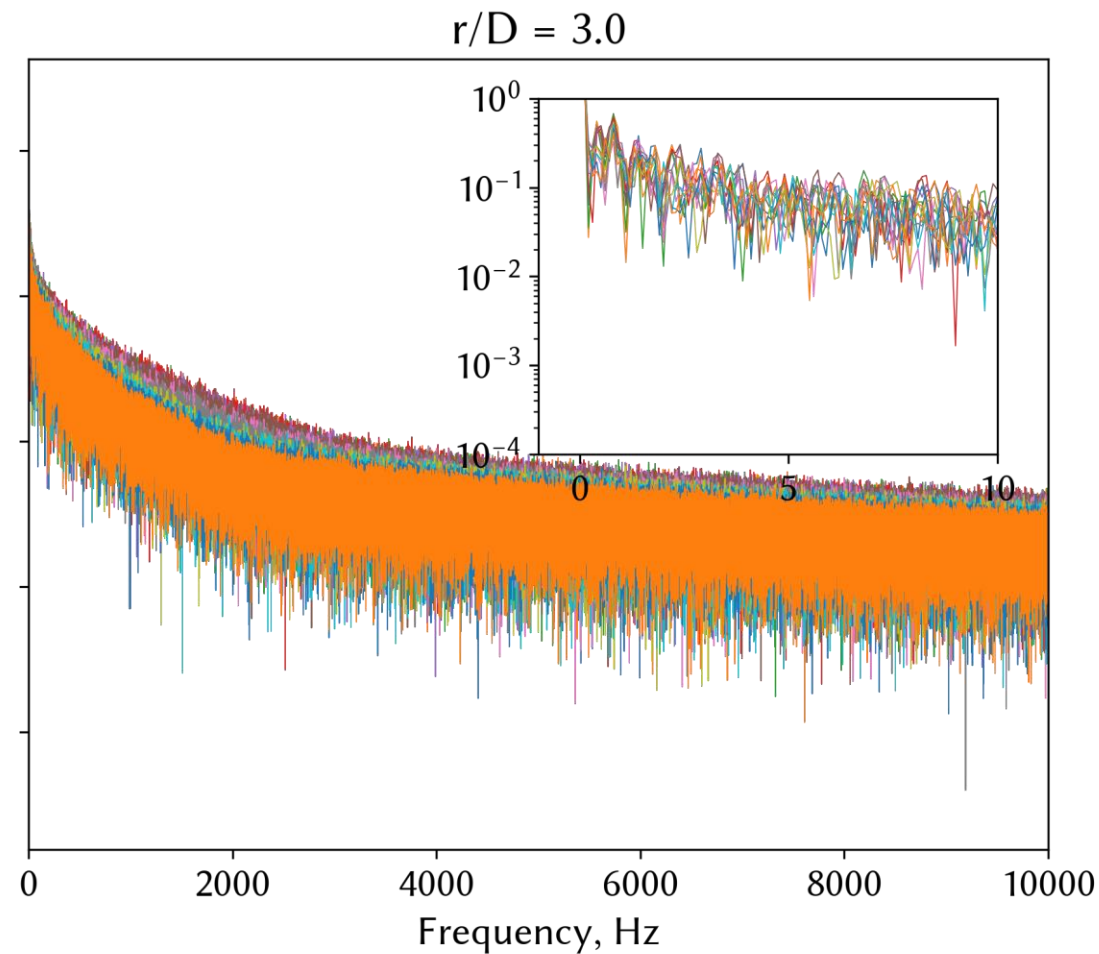
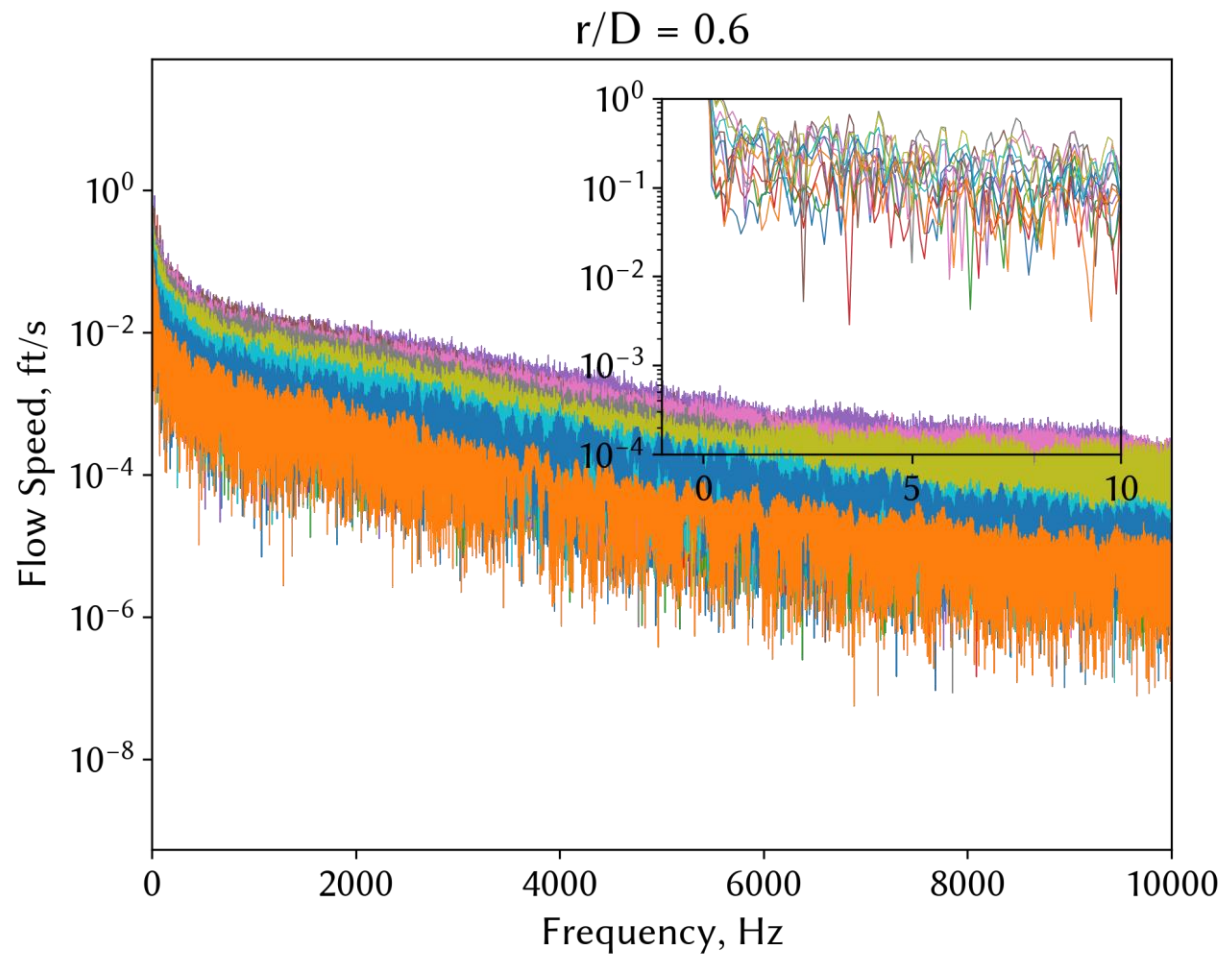


Backup

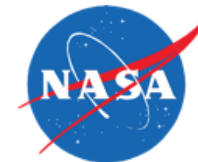
Outwash Spectral Content



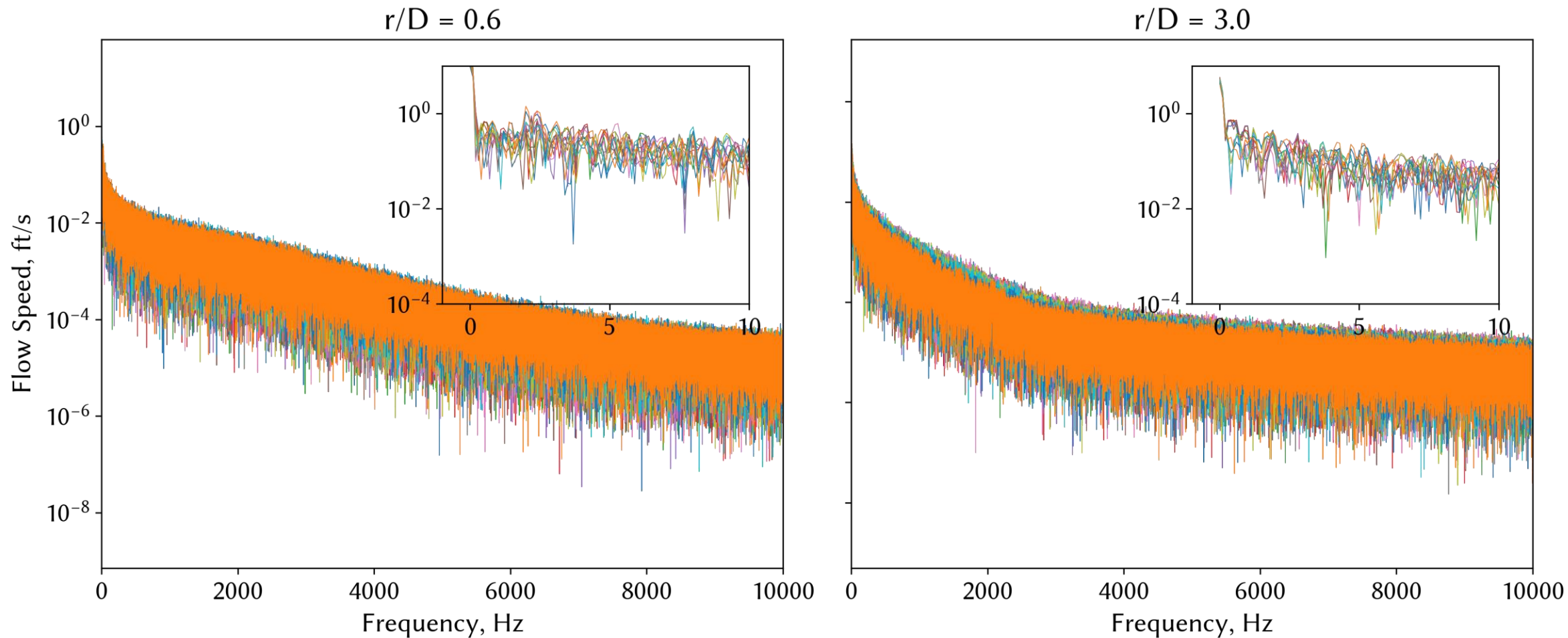
All Hot Films, $h/D = 0.4$, $C_T/\sigma = 0.06$



Outwash Spectral Content



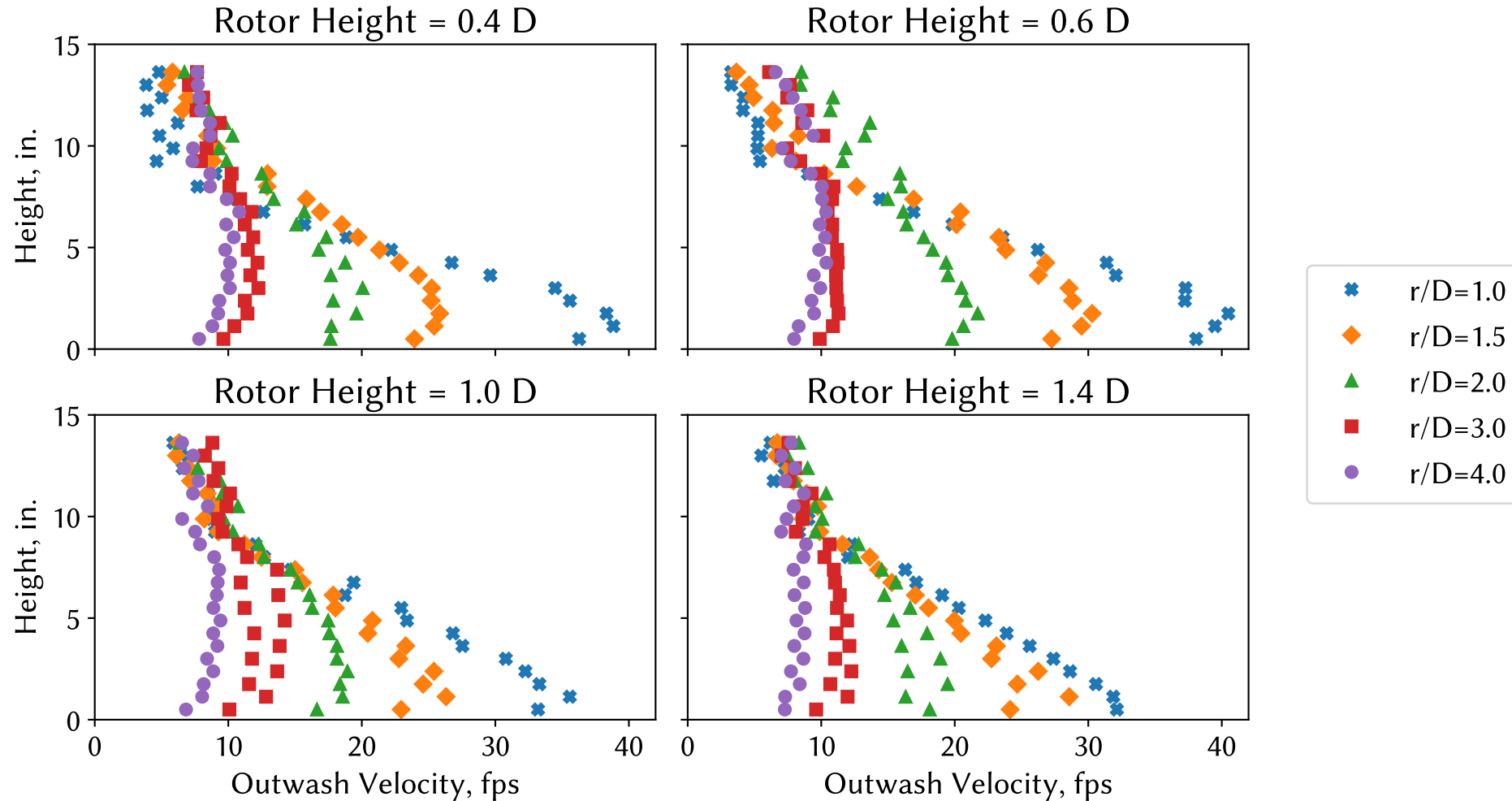
All Hot Films, $h/D = 1.0$, $C_T/\sigma = 0.06$



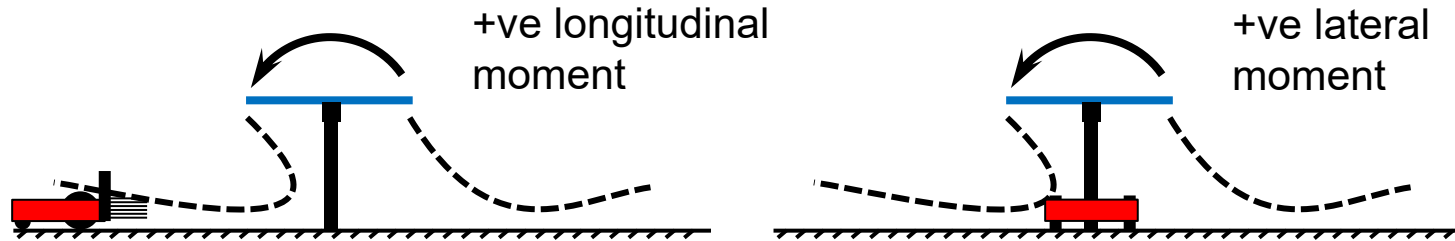
Effects of Rotor Height and Observer Distance



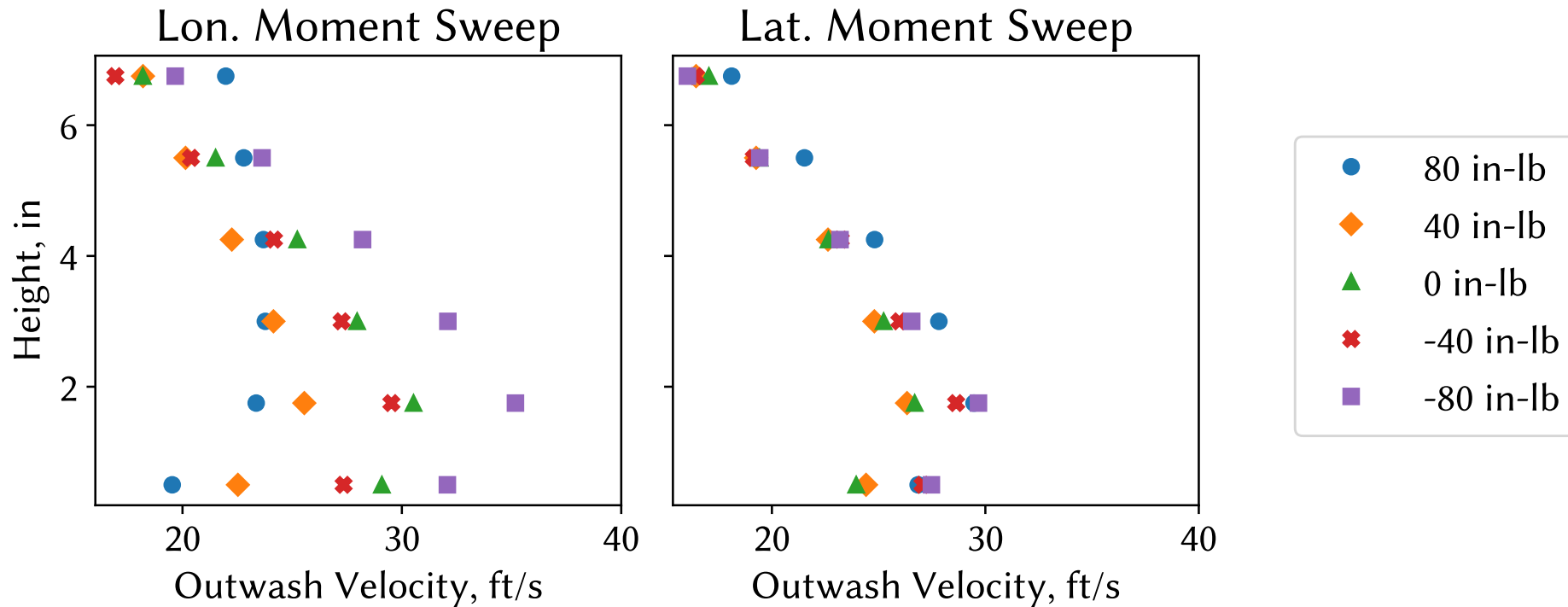
$CT/\sigma = 0.06$, Zero moment



Moment Effects on Outwash



$h/D = 0.6$, $r/D = 1.5$, $T = 40$ lb.





Outwash Propagation Characteristics

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