A-Class Catamaran Board Hydrodynamics

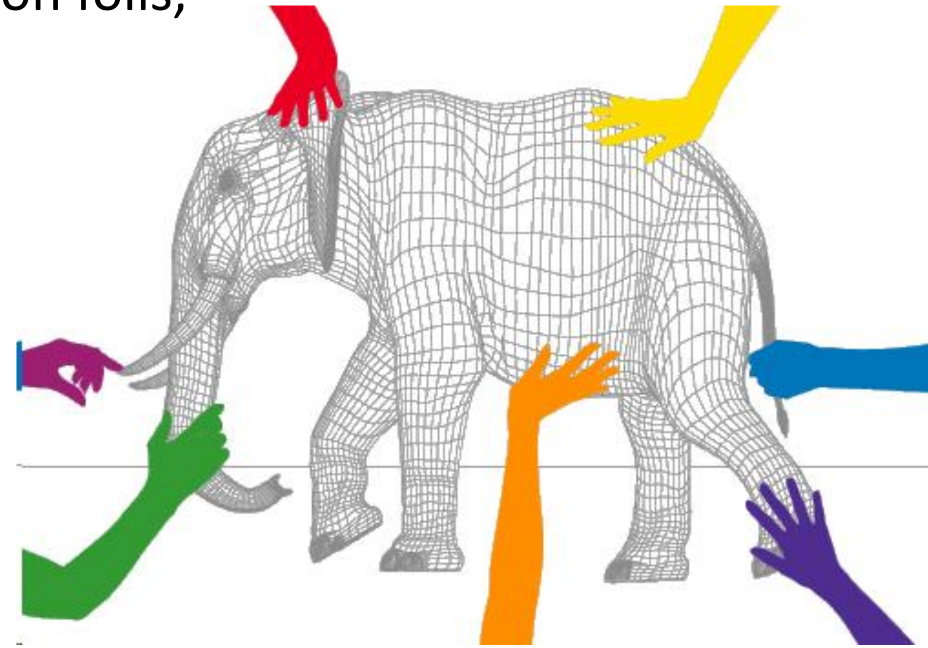
Tom Speer

http://www.tspeer.com/Aclass/A-ClassCatamaranFoils.pdf

Questions Considered

When an A-Class Catamaran is flying on foils,

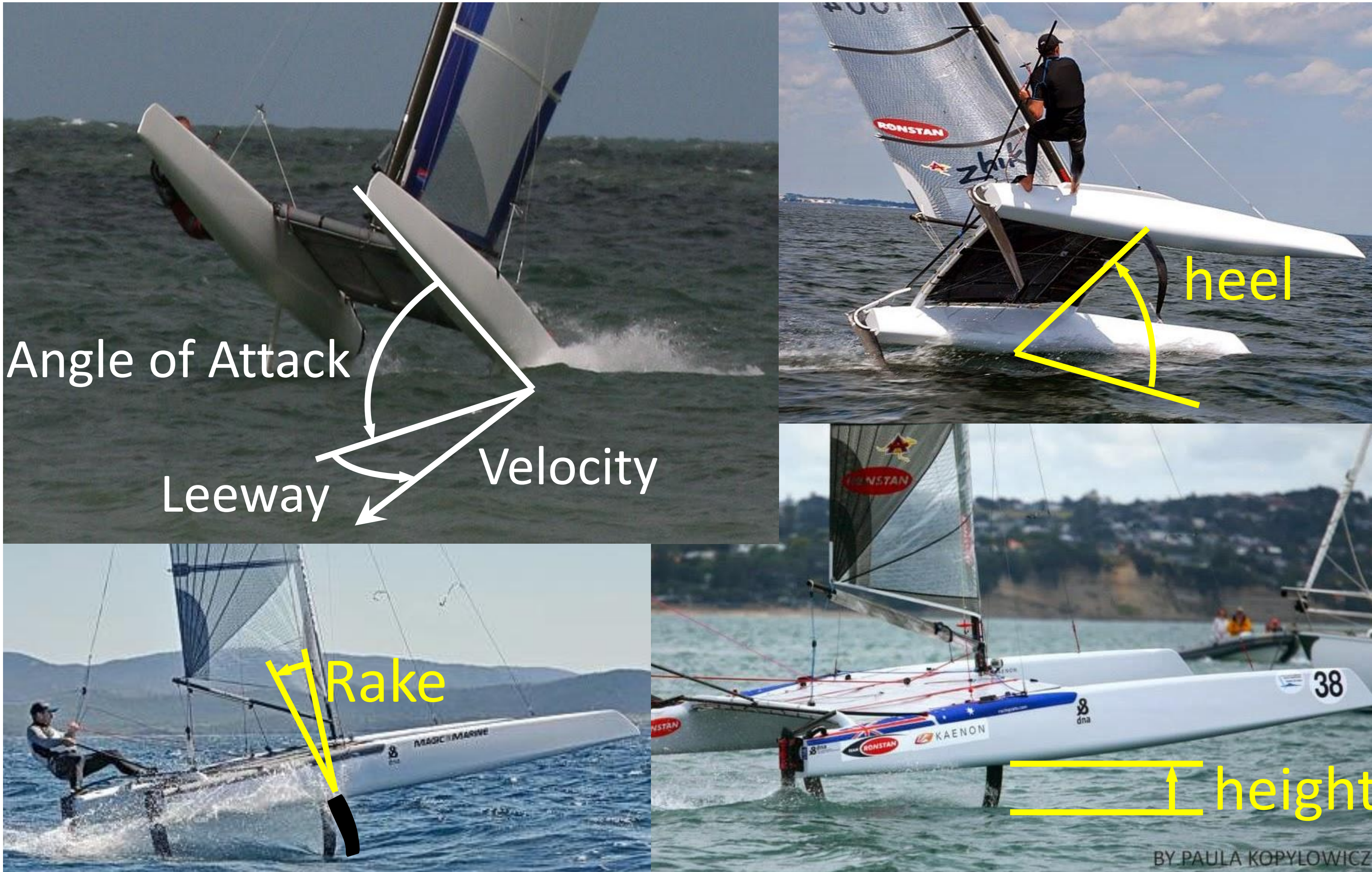
- How does board design contribute to flying stability?
- What daggerboard geometries fit the A-Class Rule?
- How do board characteristics change with curvature?
- What is the tradeoff between heave stability & drag?
- Where might A-Class board design go in the future?



Focus is on understanding, not optimization

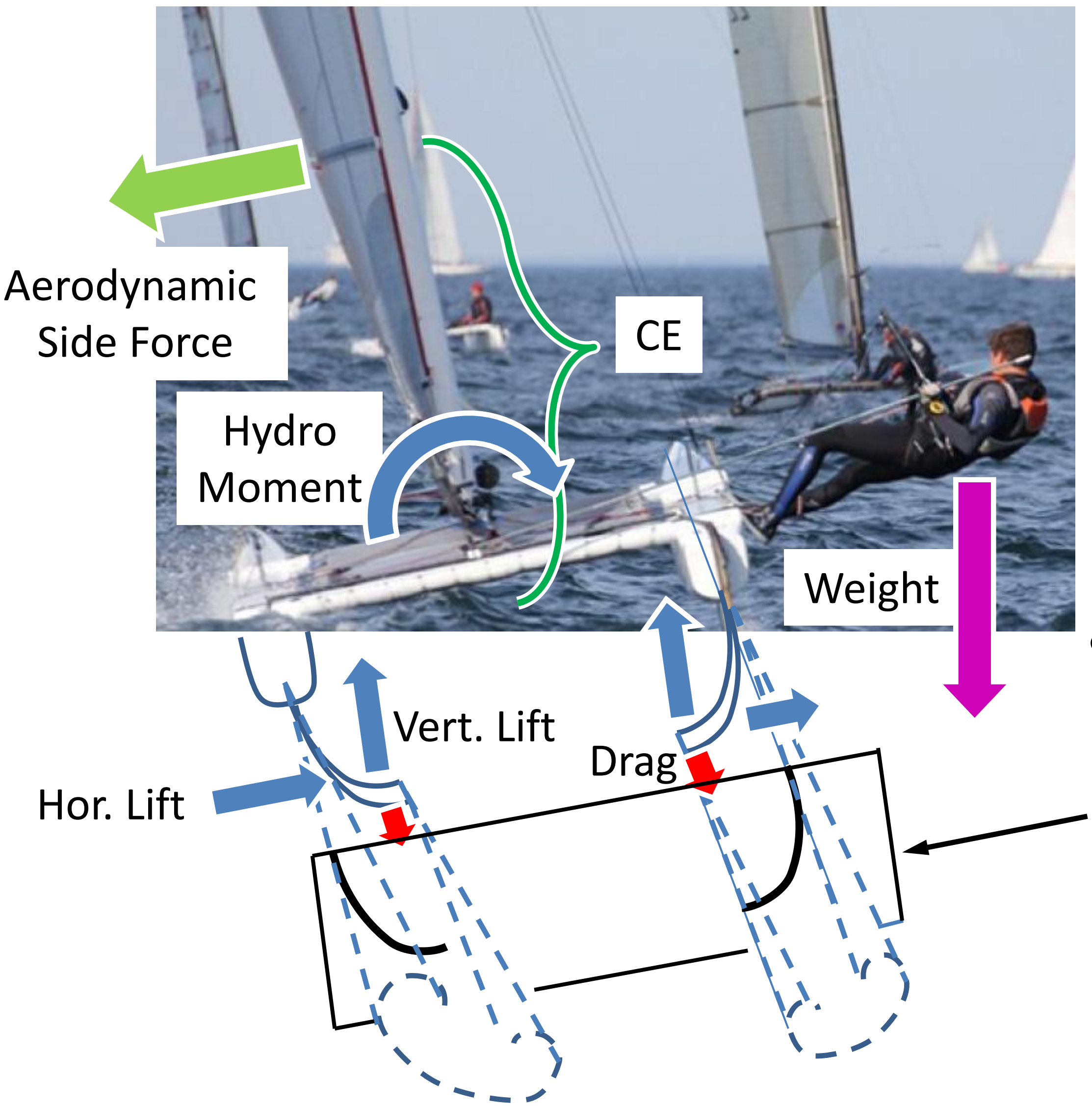
Lift-induced drag only – no profile drag, no wave drag

Terms


Angle of Attack
Leeway
Velocity
heel
Rake
height
BY PAULA KOPYLOWICZ

Requirements

Equilibrium Forces & Moments



∑Vertical Lift = Total Weight

∑Horizontal Lift = Side Force

Side Force * Center of Effort = Hydrodynamic Moment + Sailor Weight * Lever Arm

Leeway & angle of attack adjust to ensure equilibrium

Lifting line analysis considers wake shape in plane behind boards

Static Stability Requirements

- Assume sway, roll & yaw axes in equilibrium
- Start from trimmed condition
- **Heave stability**: $dFz/dh < 0$
  An increase in flying height
  at constant pitch attitude => reduction in lift
- **Pitch stability**: $dMy/d\theta < 0$
  An increase in pitch attitude
  at constant flying height => bow-down moment
- **Pitch-heave coupling**: $dMy/dh < 0$
  An increase in flying height
  at constant pitch attitude => bow-down moment

Design for Static Stability

- **Heave stability**
  - Surface piercing foils (V, ladder)
  - Active feedback control (Moth, Rave, Trifoiler)
  - Leeway-modulated lift (AC72)
- **Pitch stability**
  - Aft foil less heavily loaded than forward foil (per m^2)
  - Weight forward
- **Pitch-heave coupling**
  - Forward foil has higher heave stiffness than aft foil
  - Fully submerged aft foil (T rudders)
  - Stern-first takeoff

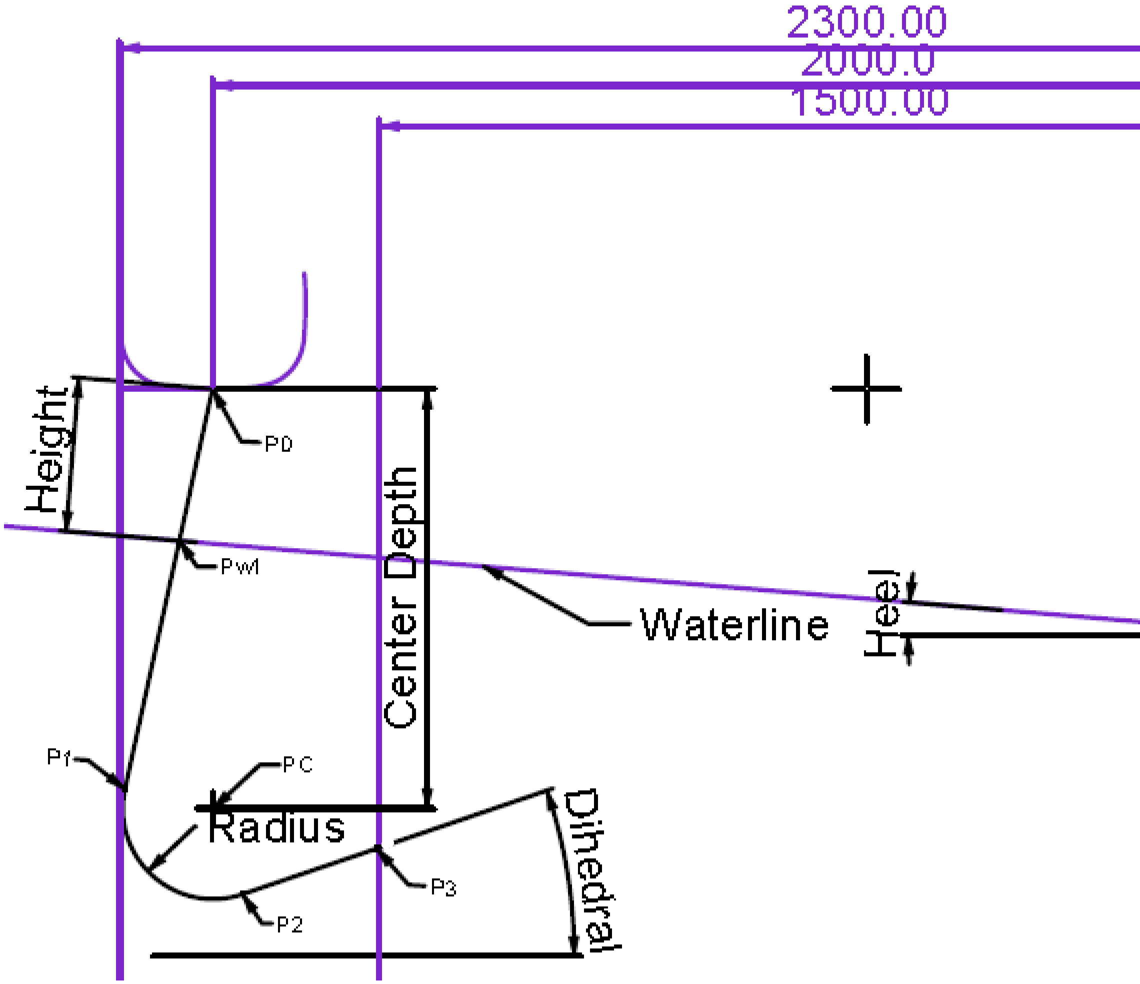
- This talk only concerns heave stability of boards

A-Class Design Requirements

- Vertical lift = 160 kg
  - 75 kg boat
  - 85 kg crew
- Righting moment (about centerline) = 180 kg m
- Height of center of effort = 2.5 m (assumed)
- A-Class span limits
  - Beam < 2.3 m
  - Foils > 0.75m from centerline
- Exit from hull ~ 1.0 m from centerline
  - Demihull beam <0.3m
- Rigid boards are assumed
- Port-starboard symmetry

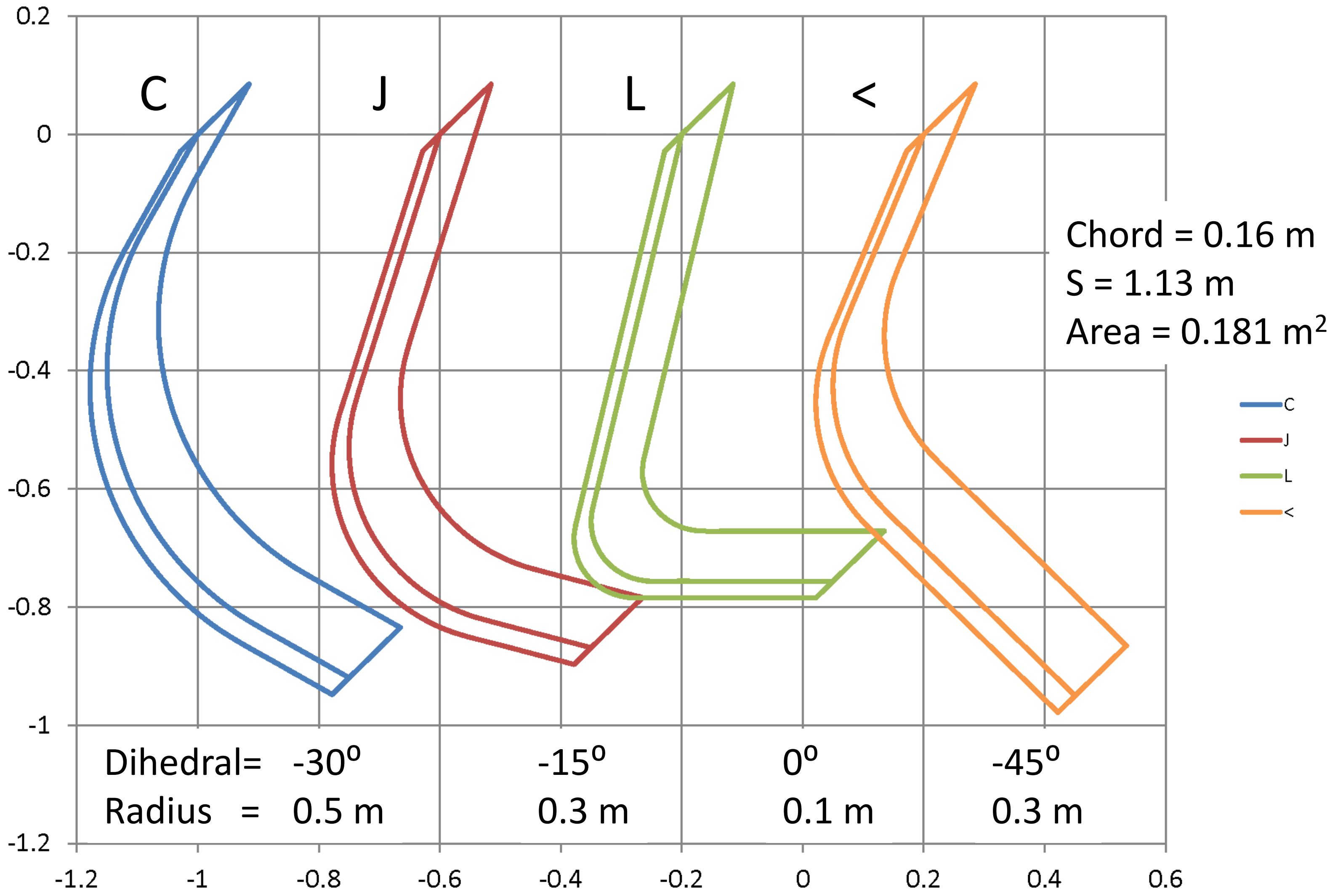
Design Parameters

- Geometry
  - Trunk location
  - Center depth
  - Bend radius
  - Wing dihedral
  - Board chord
  - Wing tip chord
- Operating Conditions
  - Flying height (h)
  - Heel angle (0, 10)
  - Speed (15 kt)

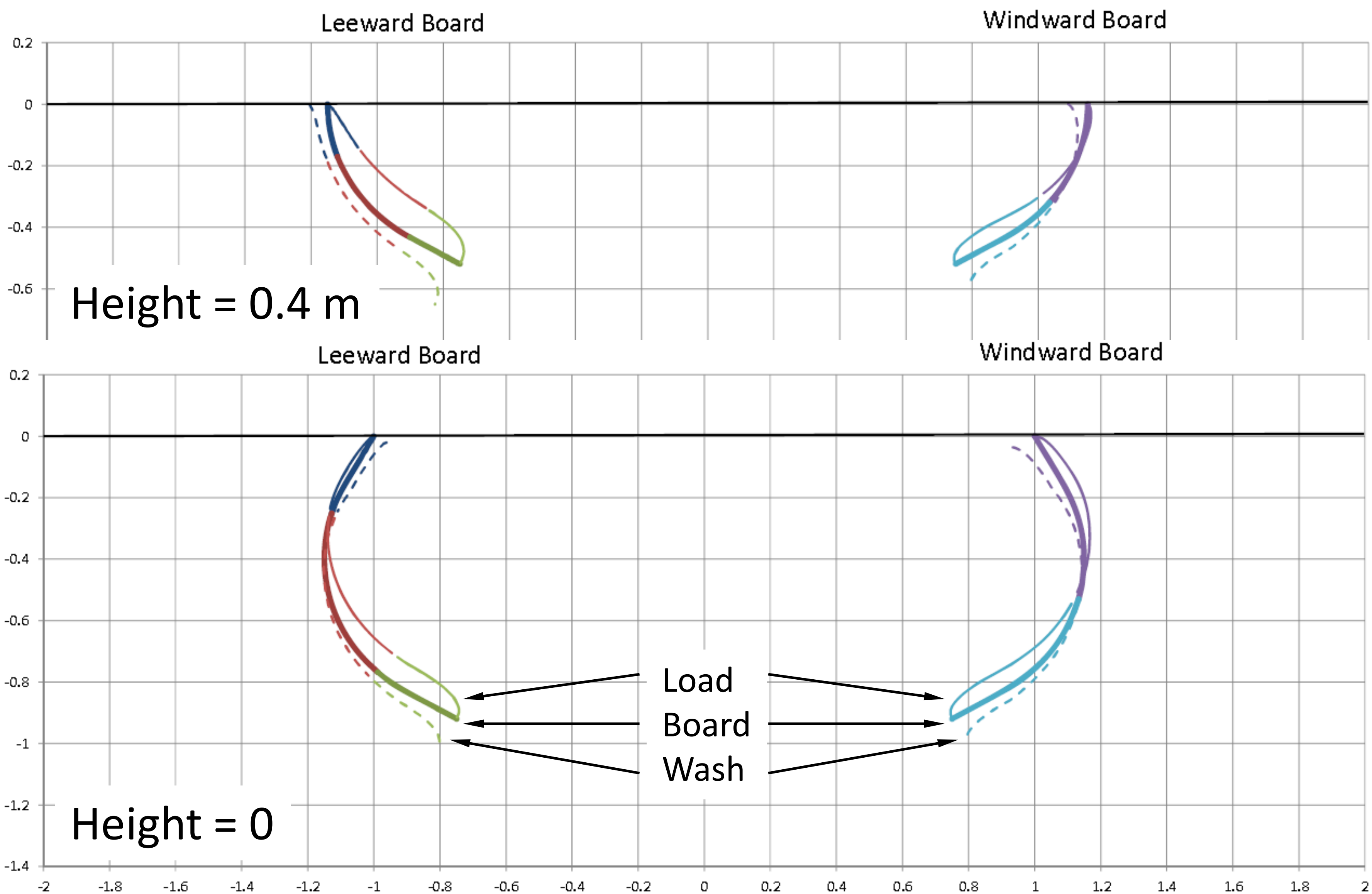


On to Foils!

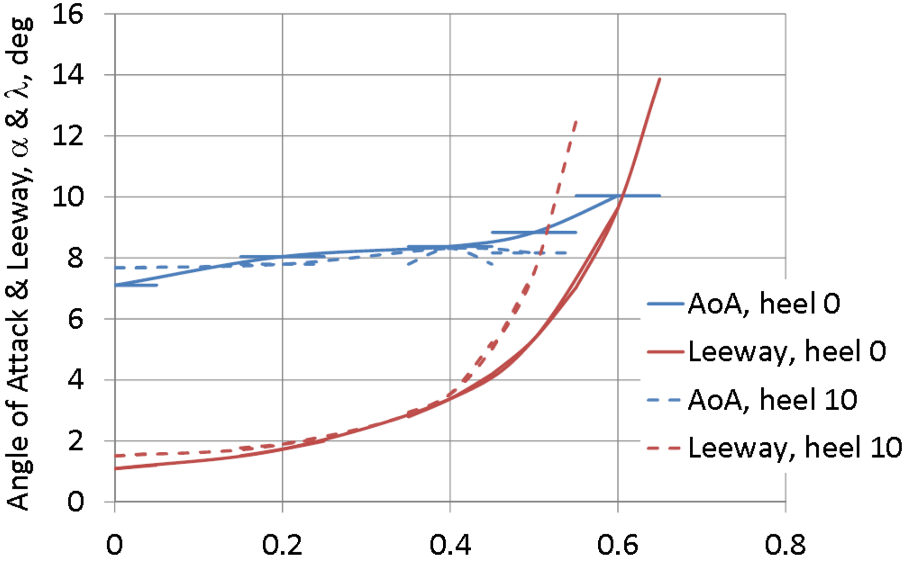
Shapes Considered

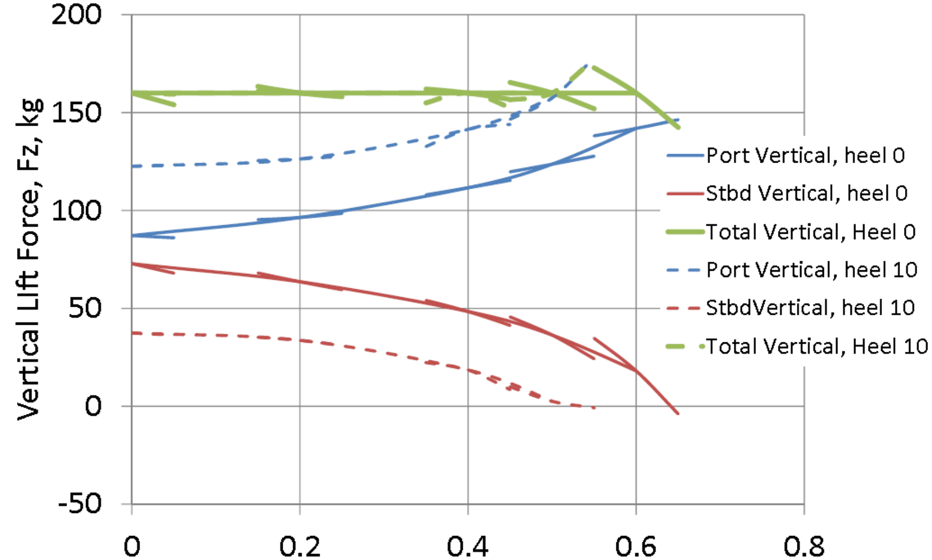


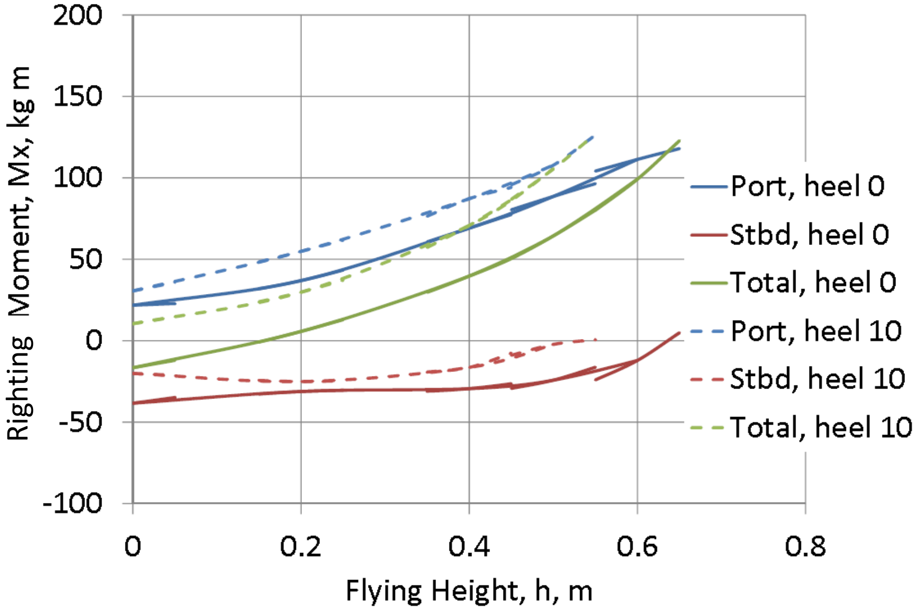
C Board Load Distributions

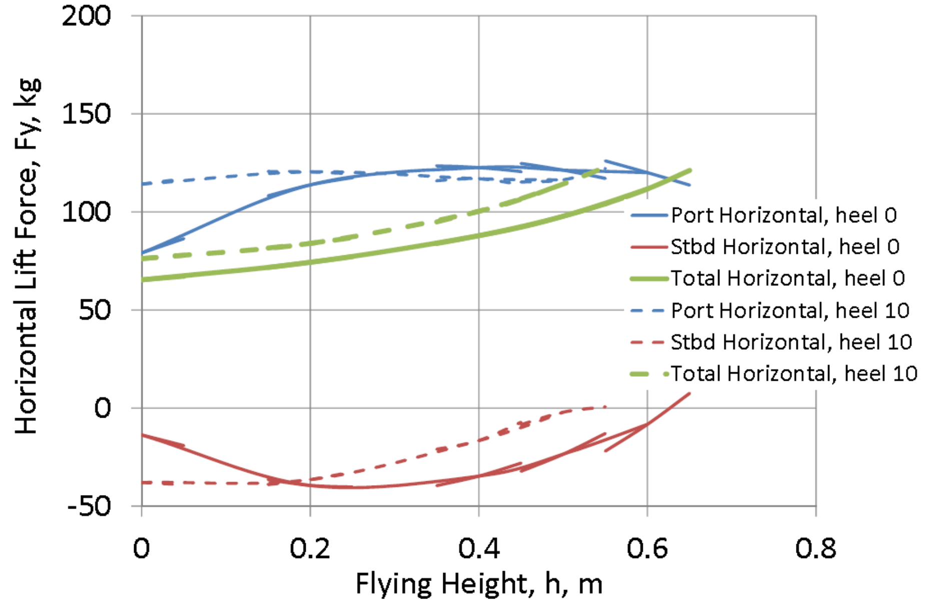


C Board Characteristics

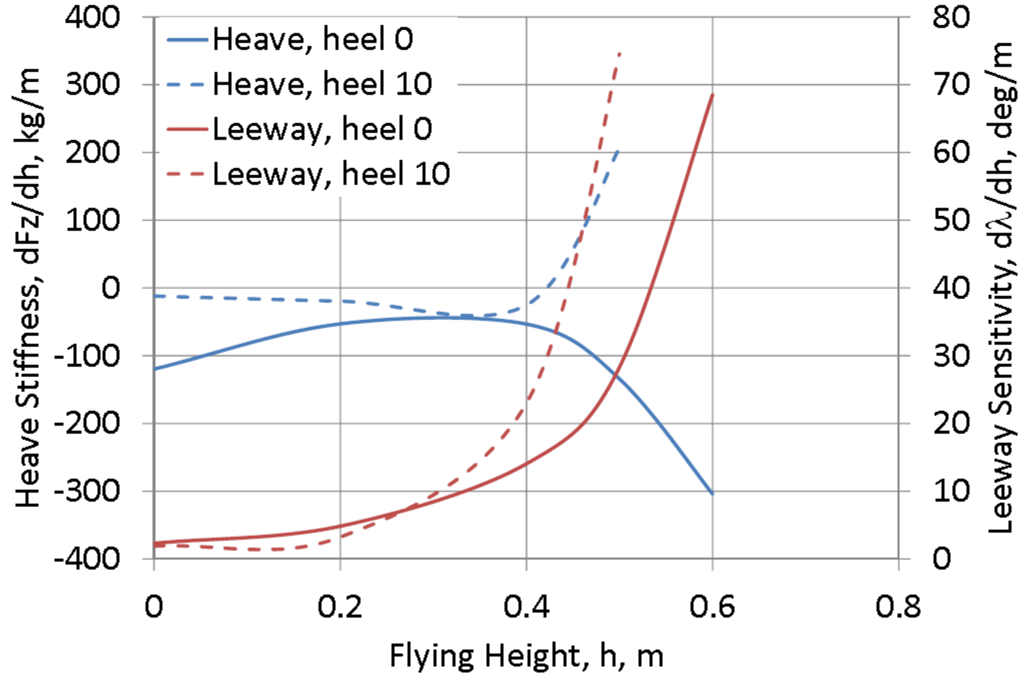




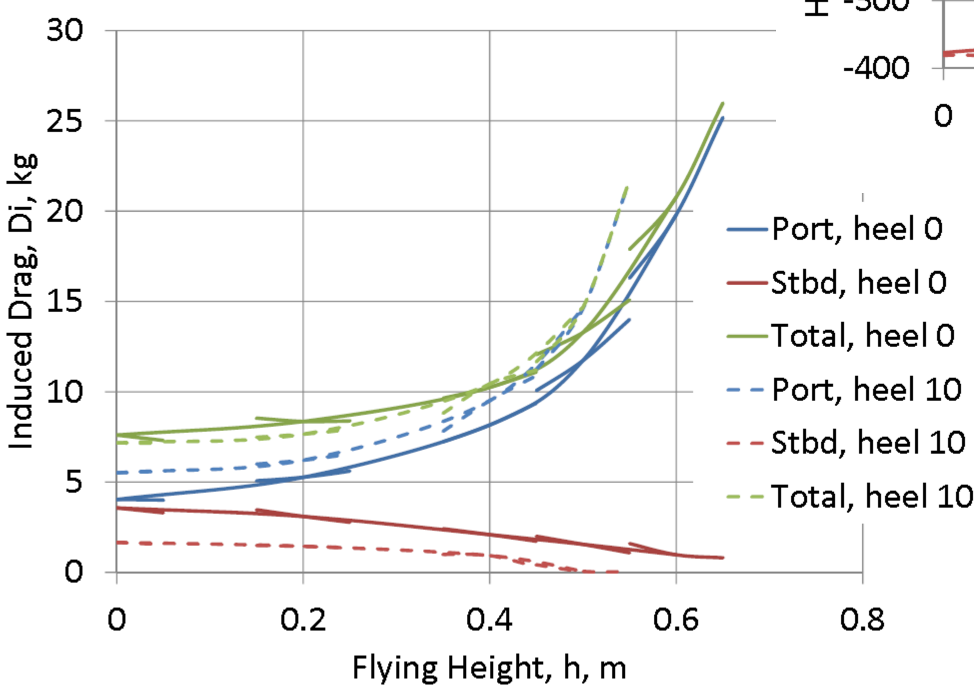




C Board Stability & Drag

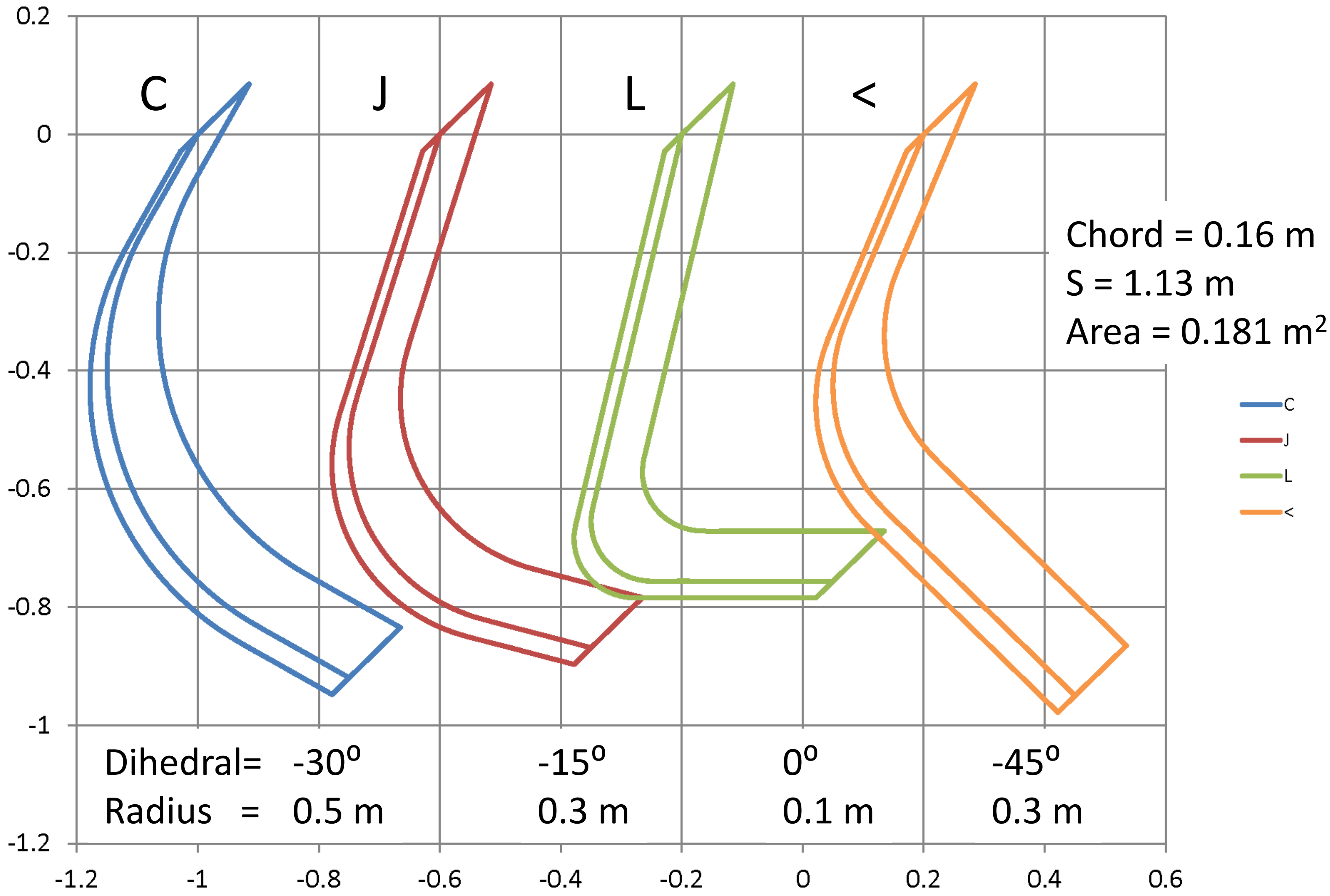


- Leeway increases as boat flies higher
- Stability initially decreases as boat flies higher

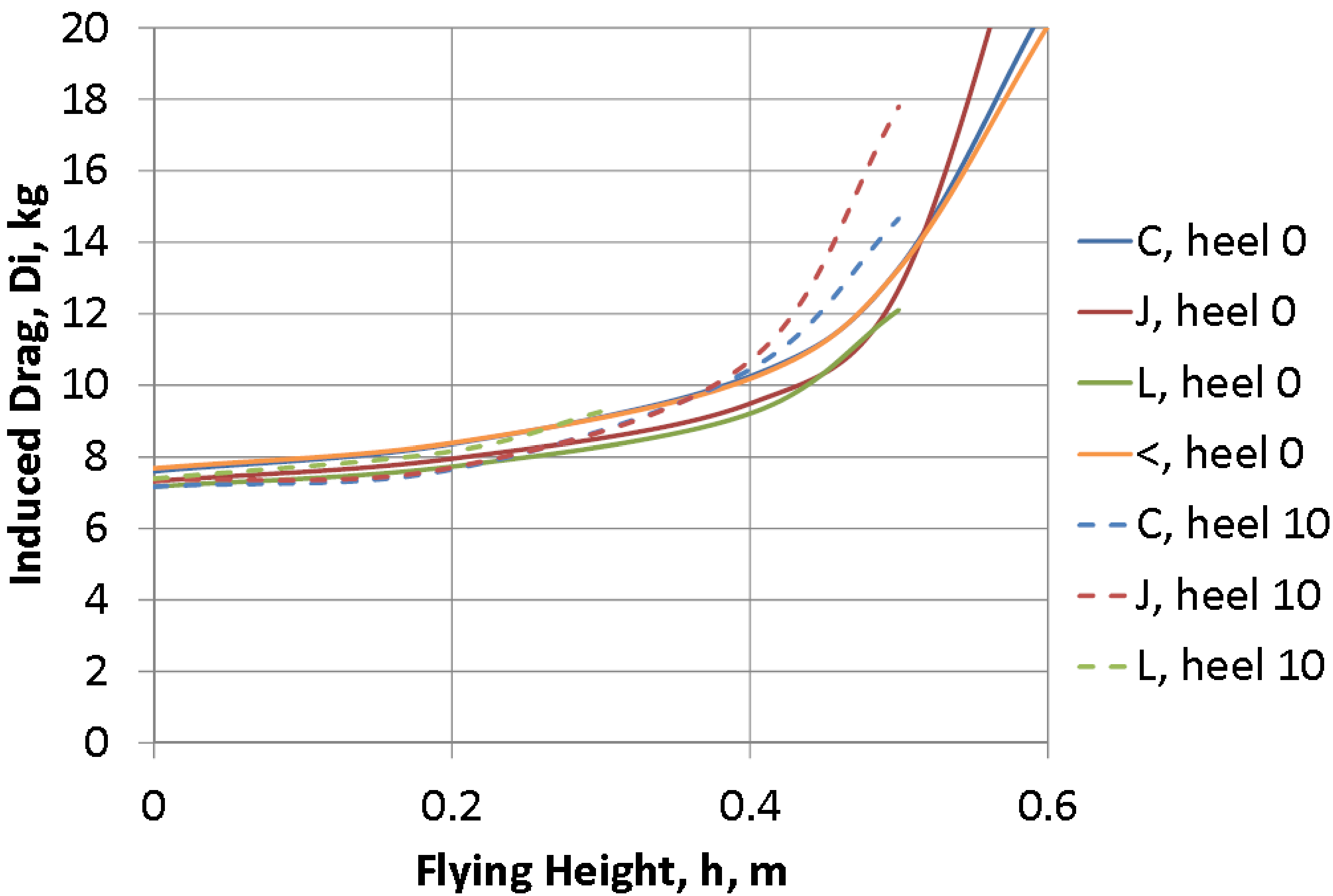


- Drag increases as boat flies higher
- Lift and drag shift to leeward board

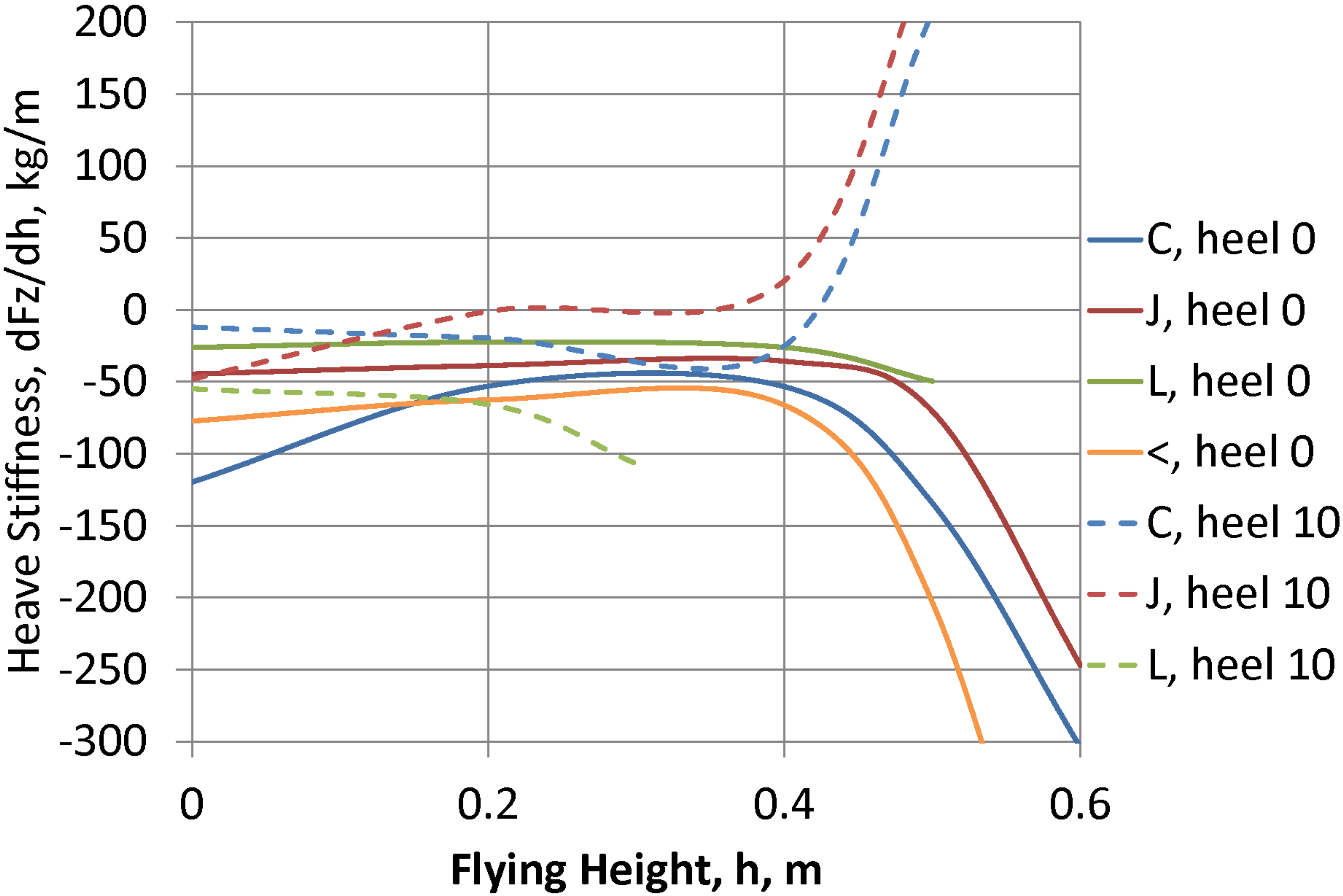
Shapes Considered



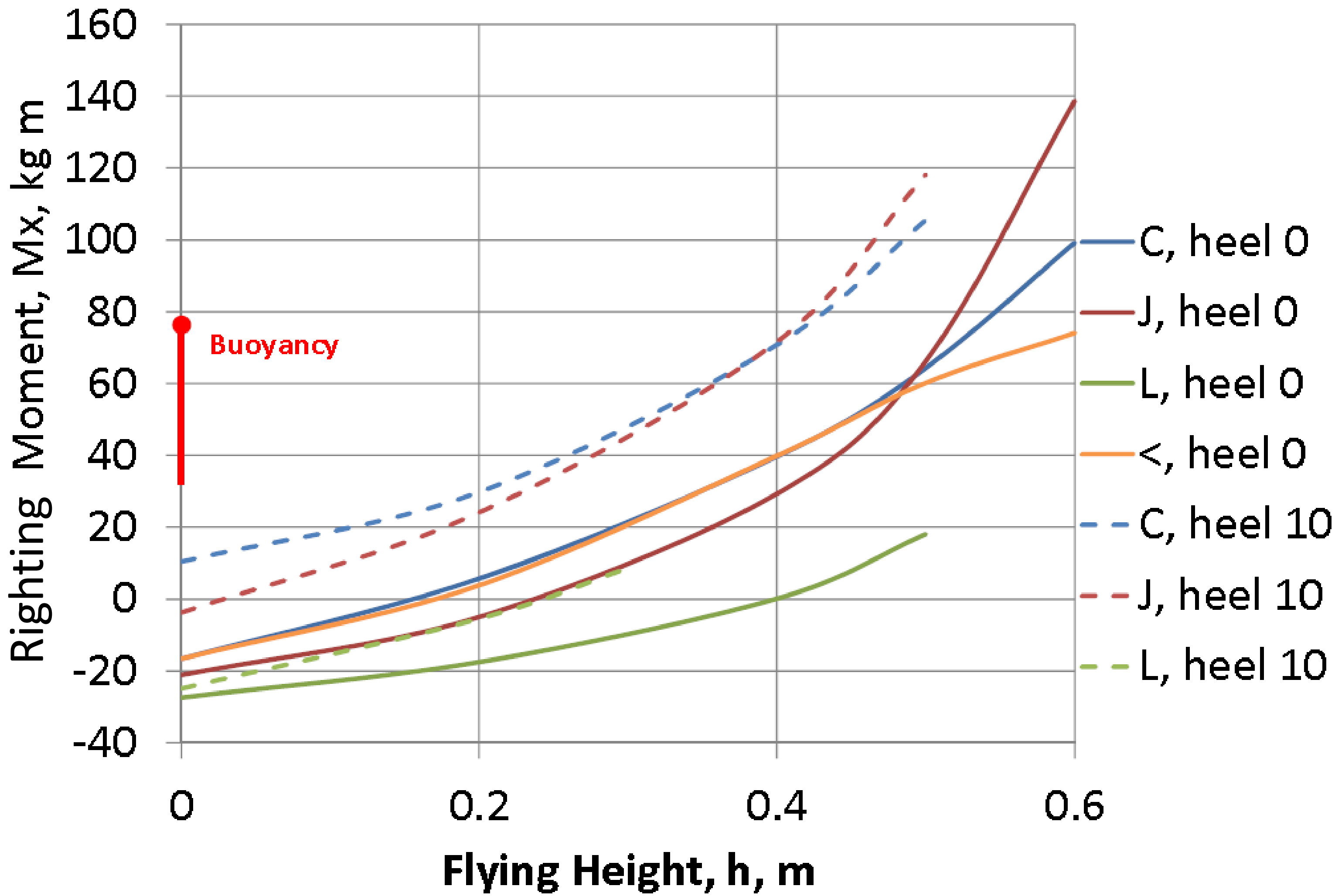
Board Drag Comparisons



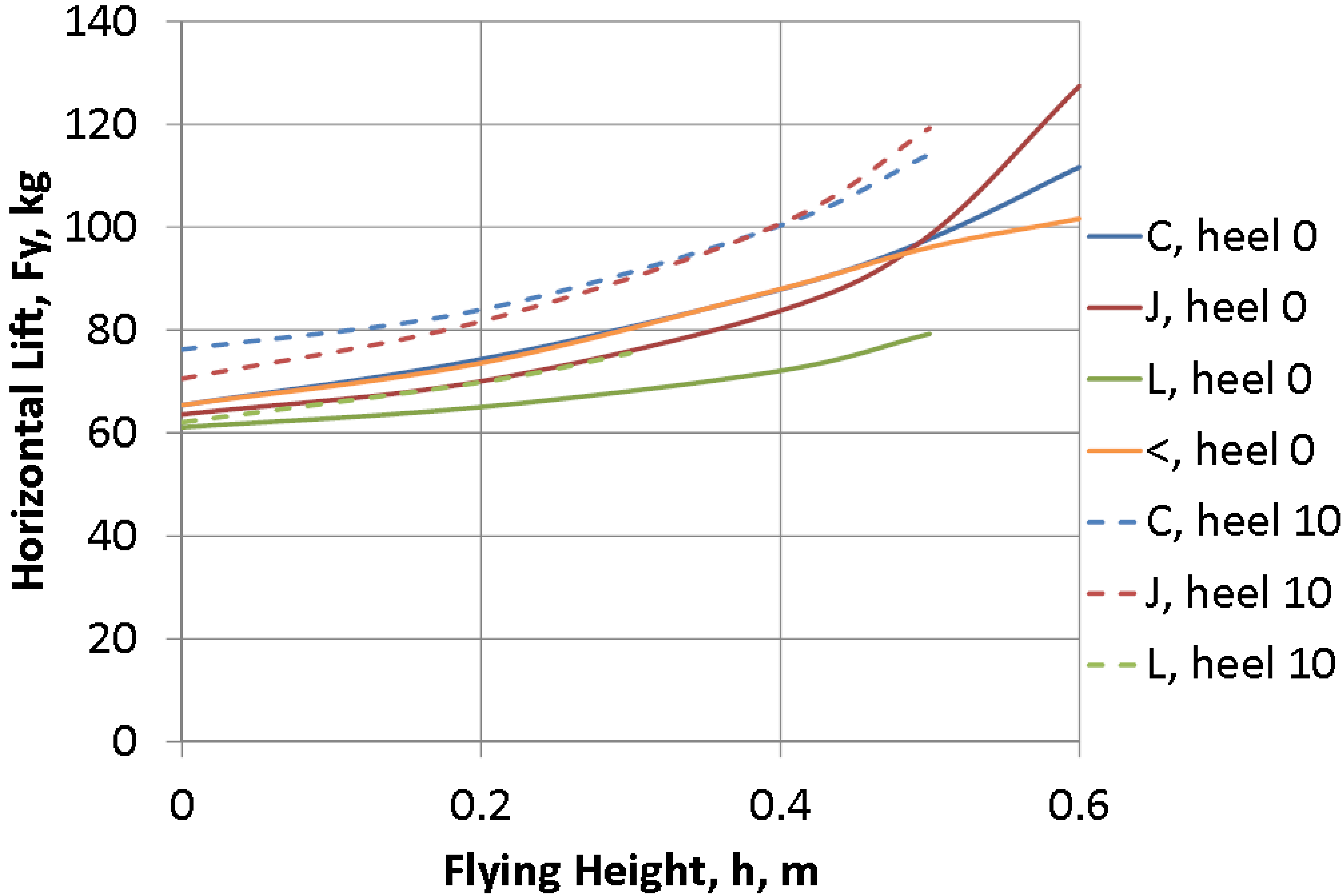
Board Stability Comparisons



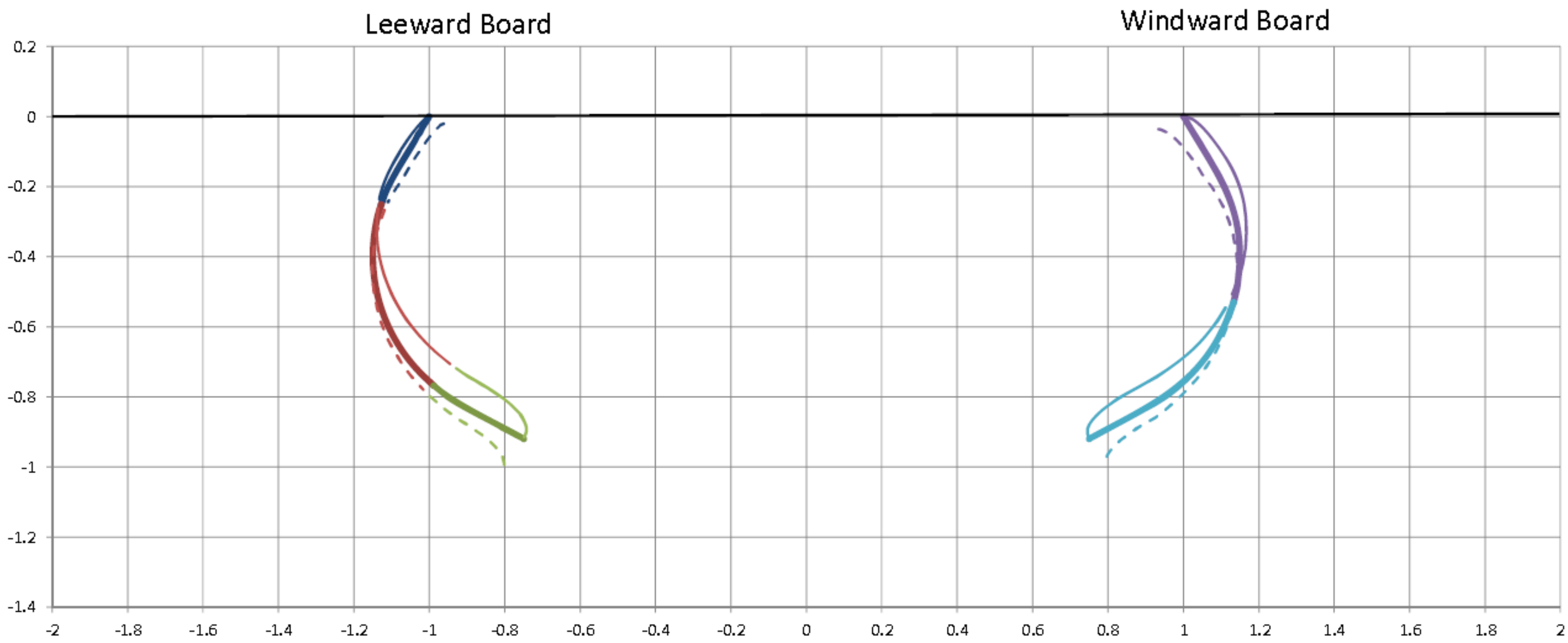
Righting Moment Comparisons



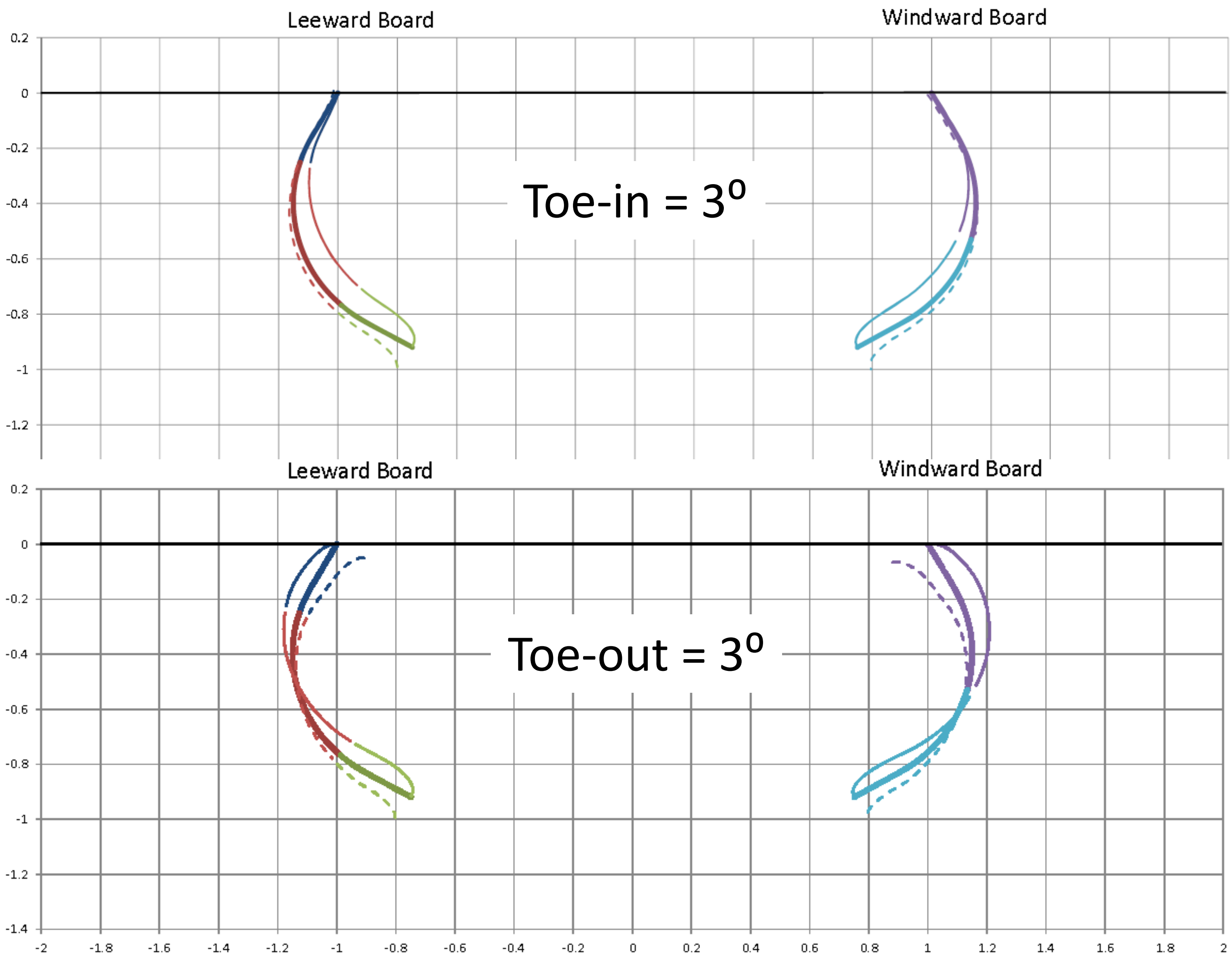
Side Force Comparisons



C Board Loading



Effect of Toe-In/Out



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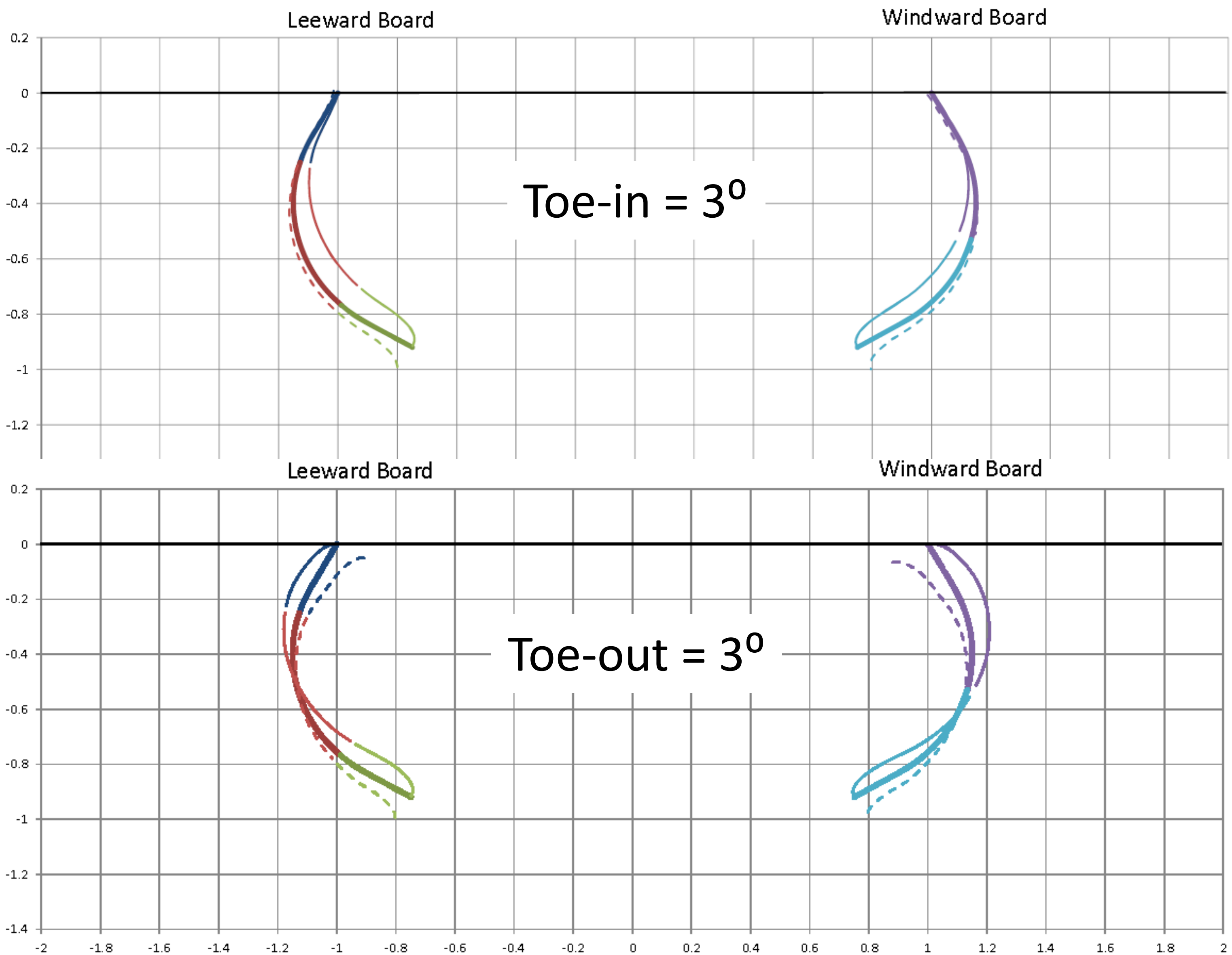

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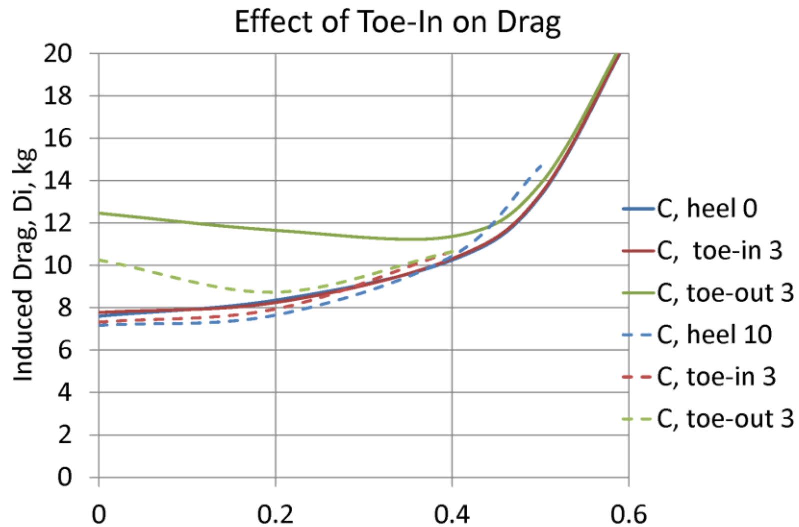
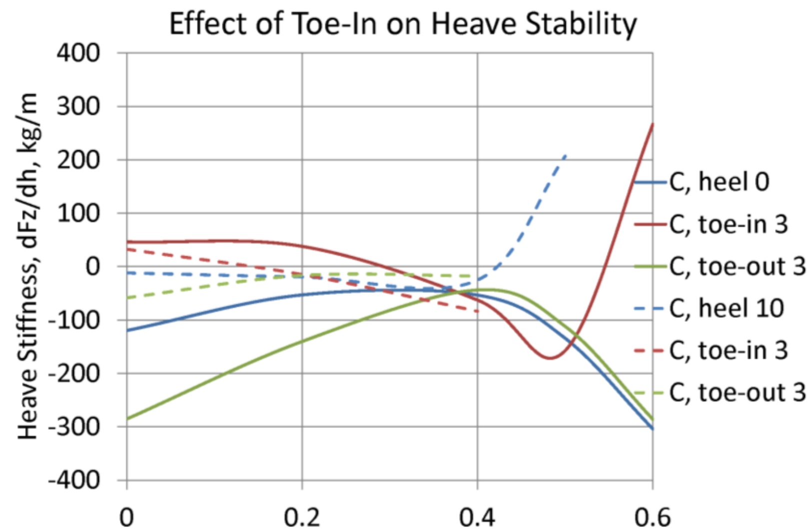
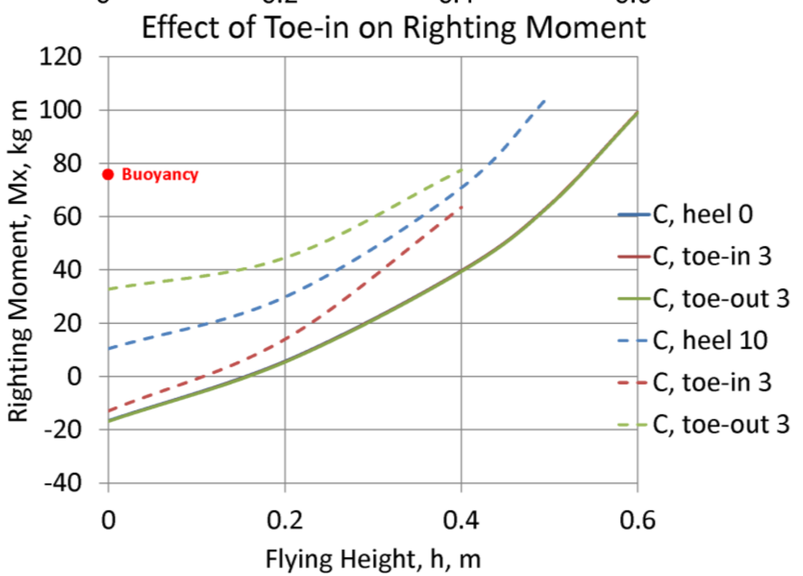
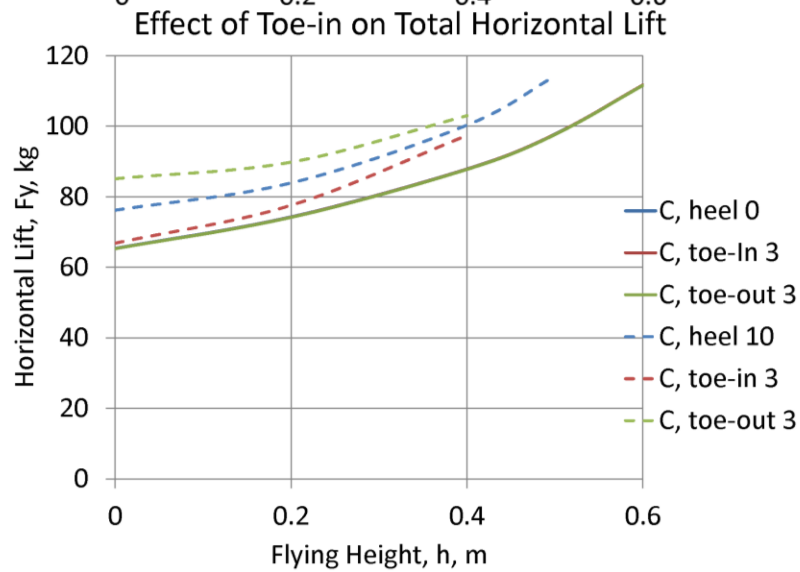
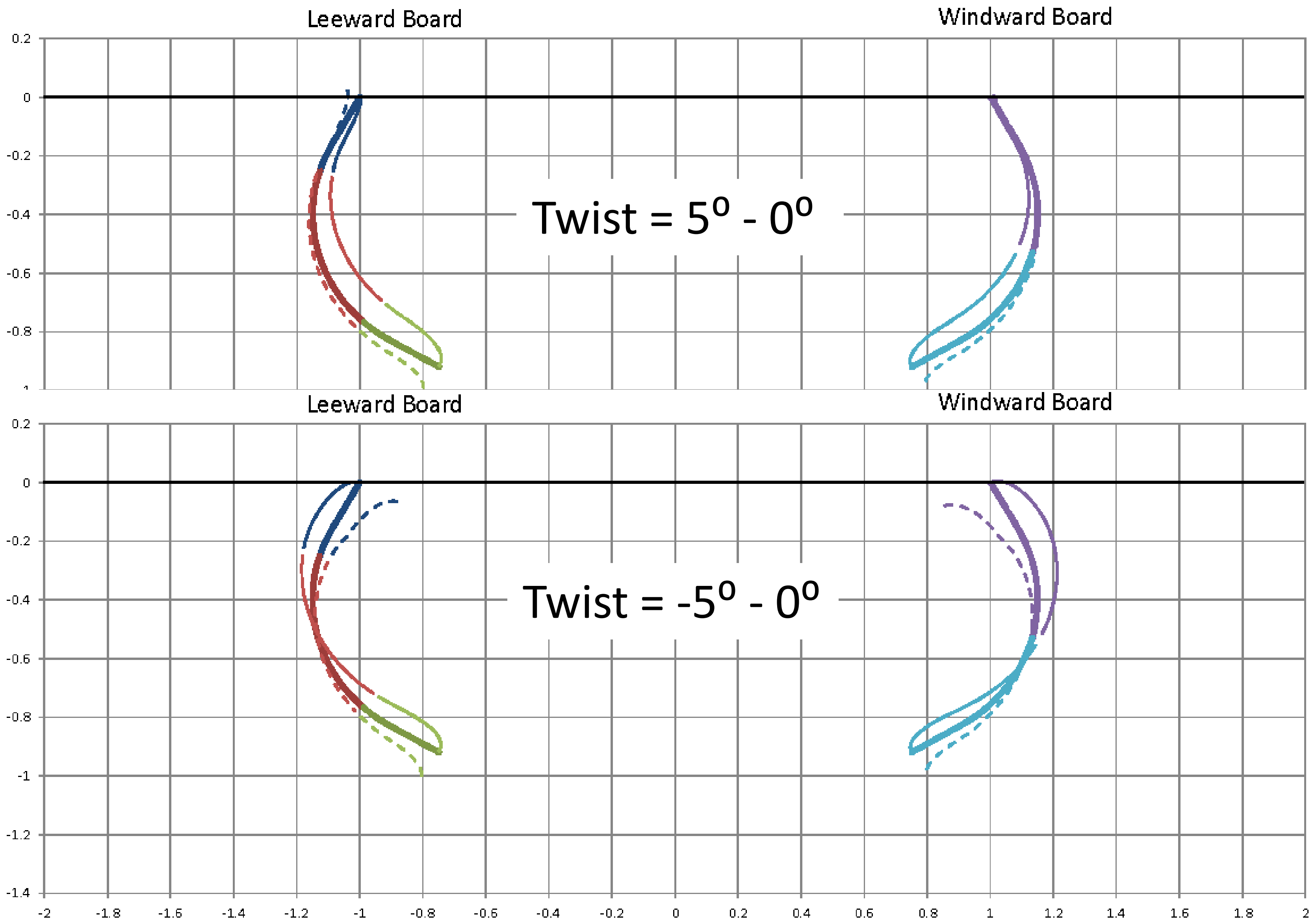




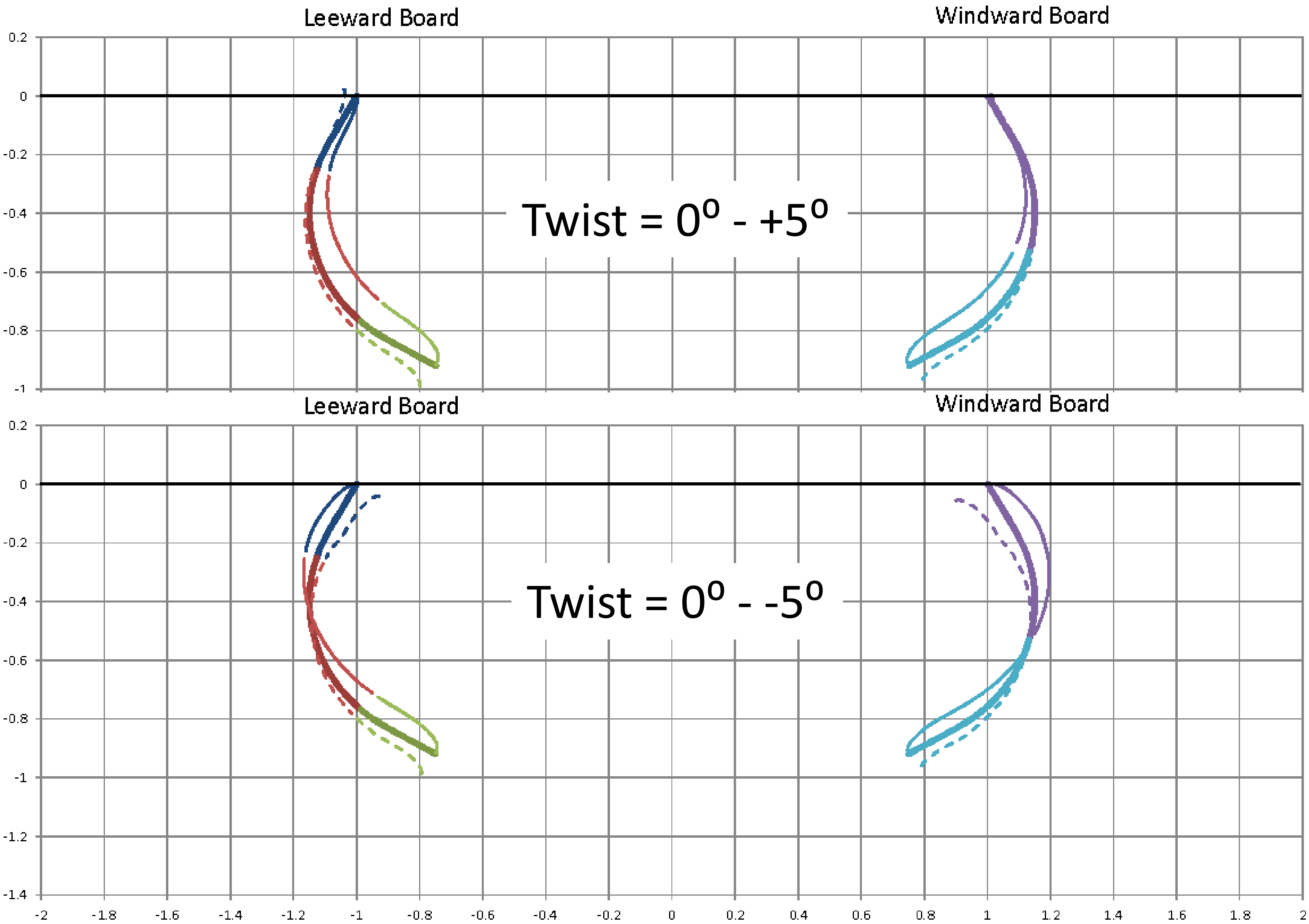




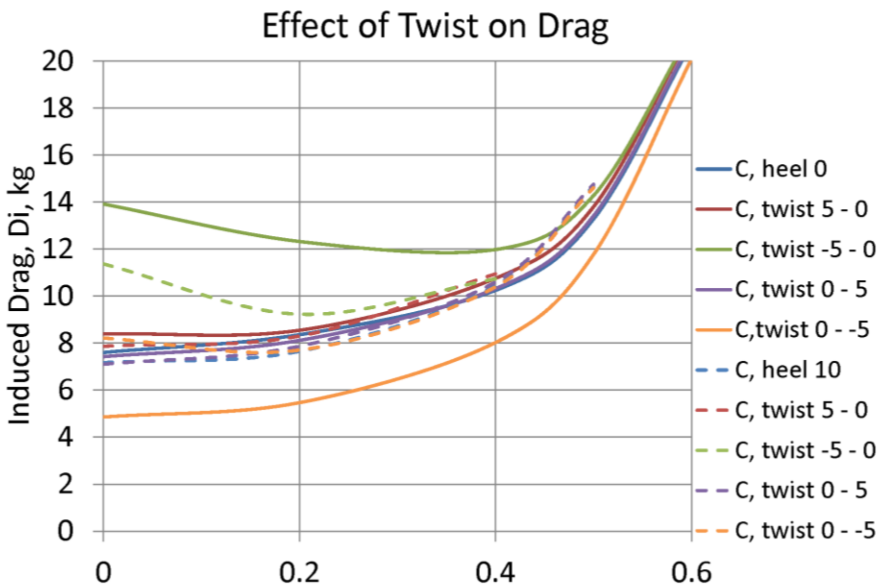
Effect of Twist at Top

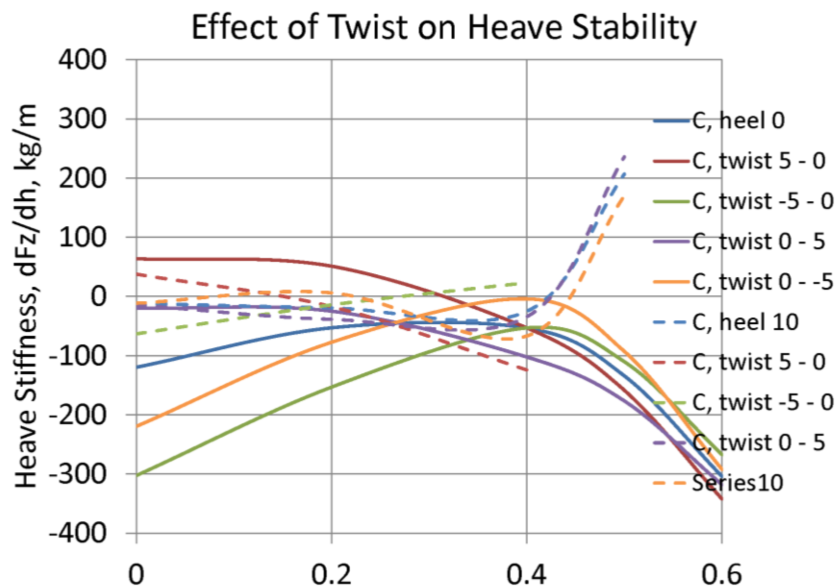


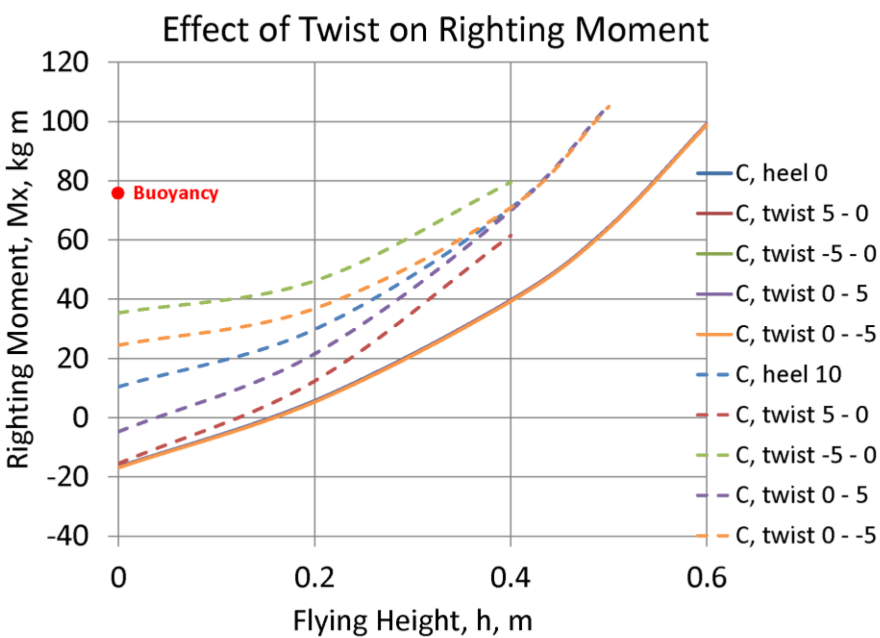
Effect of Twist at Bottom

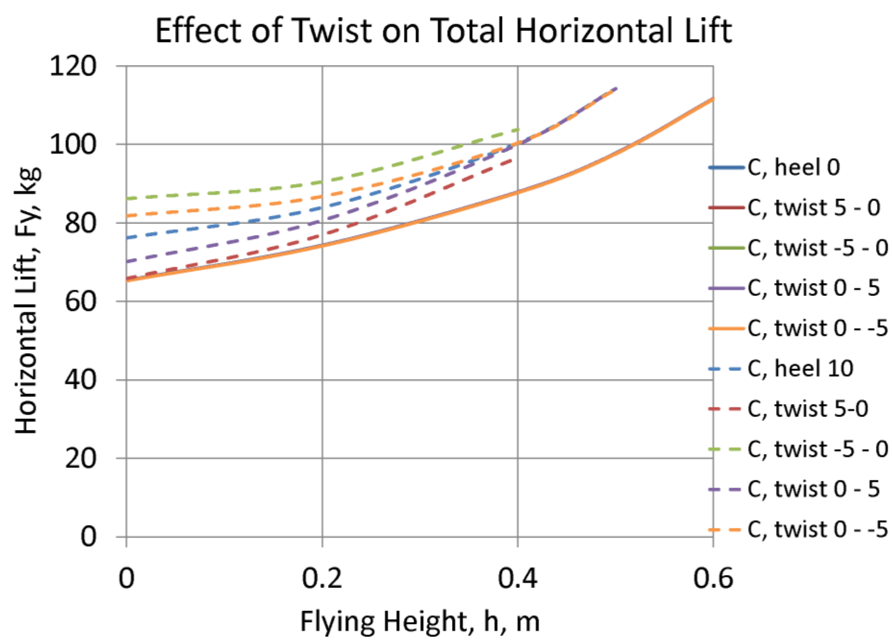


Effect of Twist

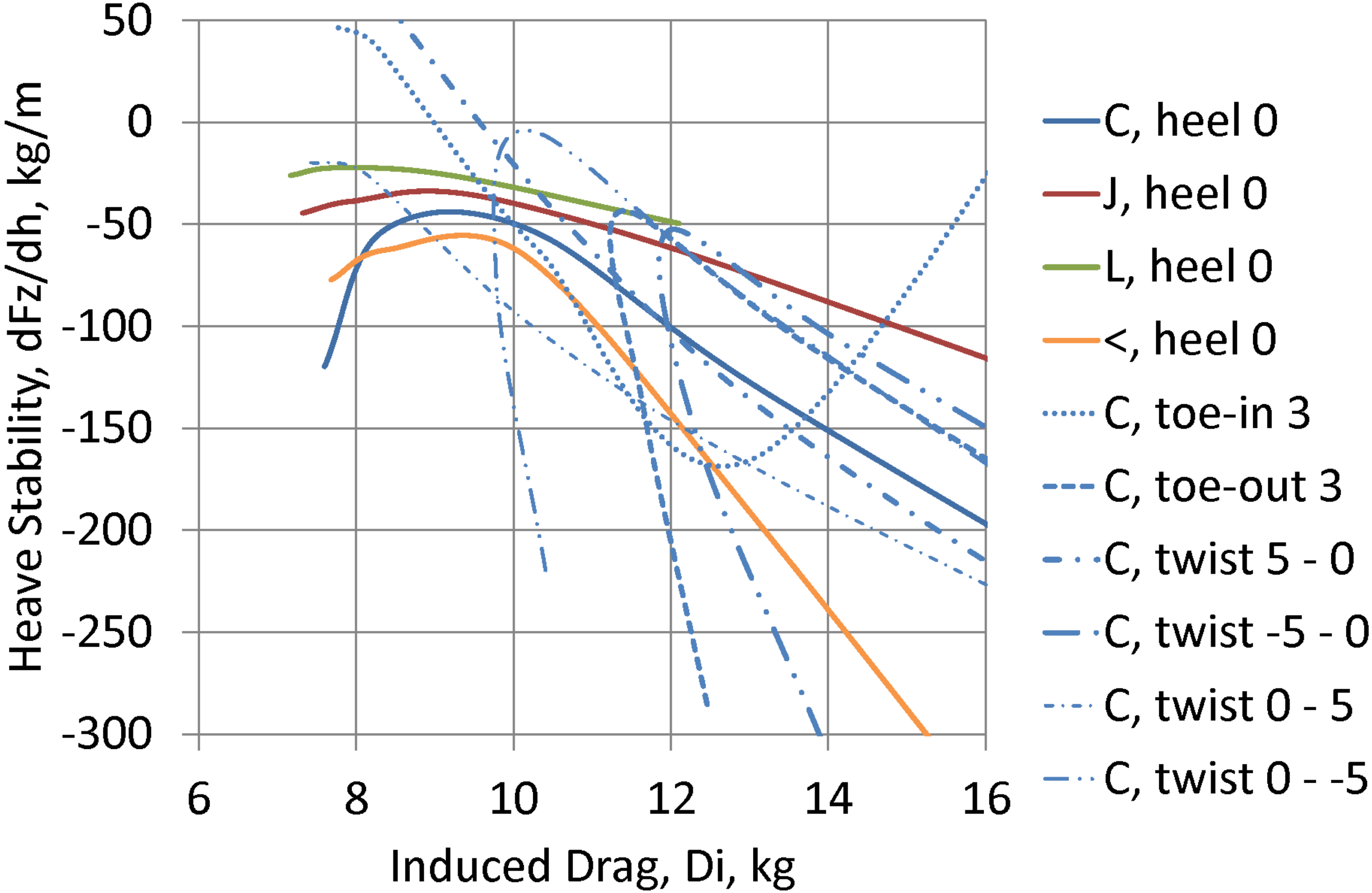








Heave Stability vs Drag Tradeoff

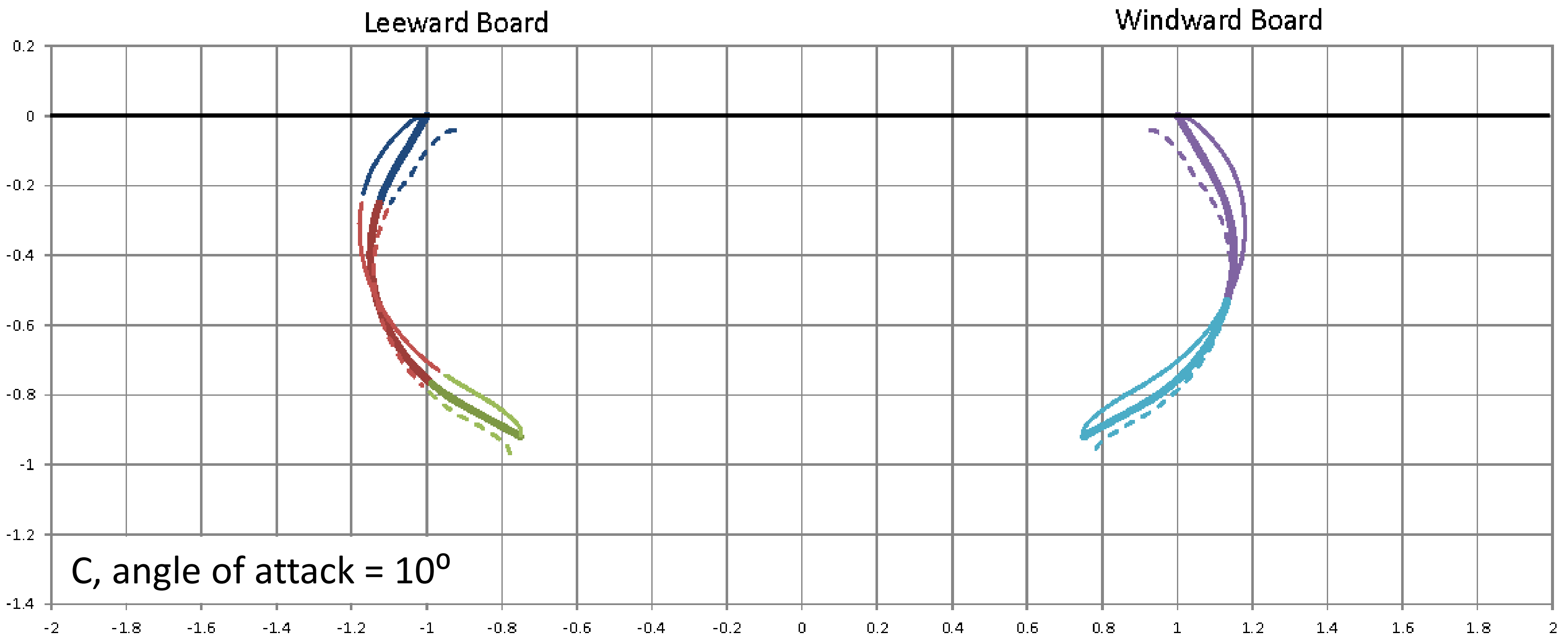


What the Elephant Looks Like So Far

- **C, J, L, < shapes investigated with lifting line**
  - Allowable sail power is significantly reduced
  - Twin foils + symmetry = loss of righting moment
- **Anhedral improves stability, adds drag** (both boards in water)
- **Heeling to leeward is destabilizing but adds sail power**
- **For C boards:**
  - Toe-in is destabilizing
    - No effect on drag or sail power
  - Toe-out is stabilizing
    - Increases sail power, but large drag penalty
  - Wash-out reduces drag of rectangular planform
    - No effect of twist on sail power
    - Stability improved

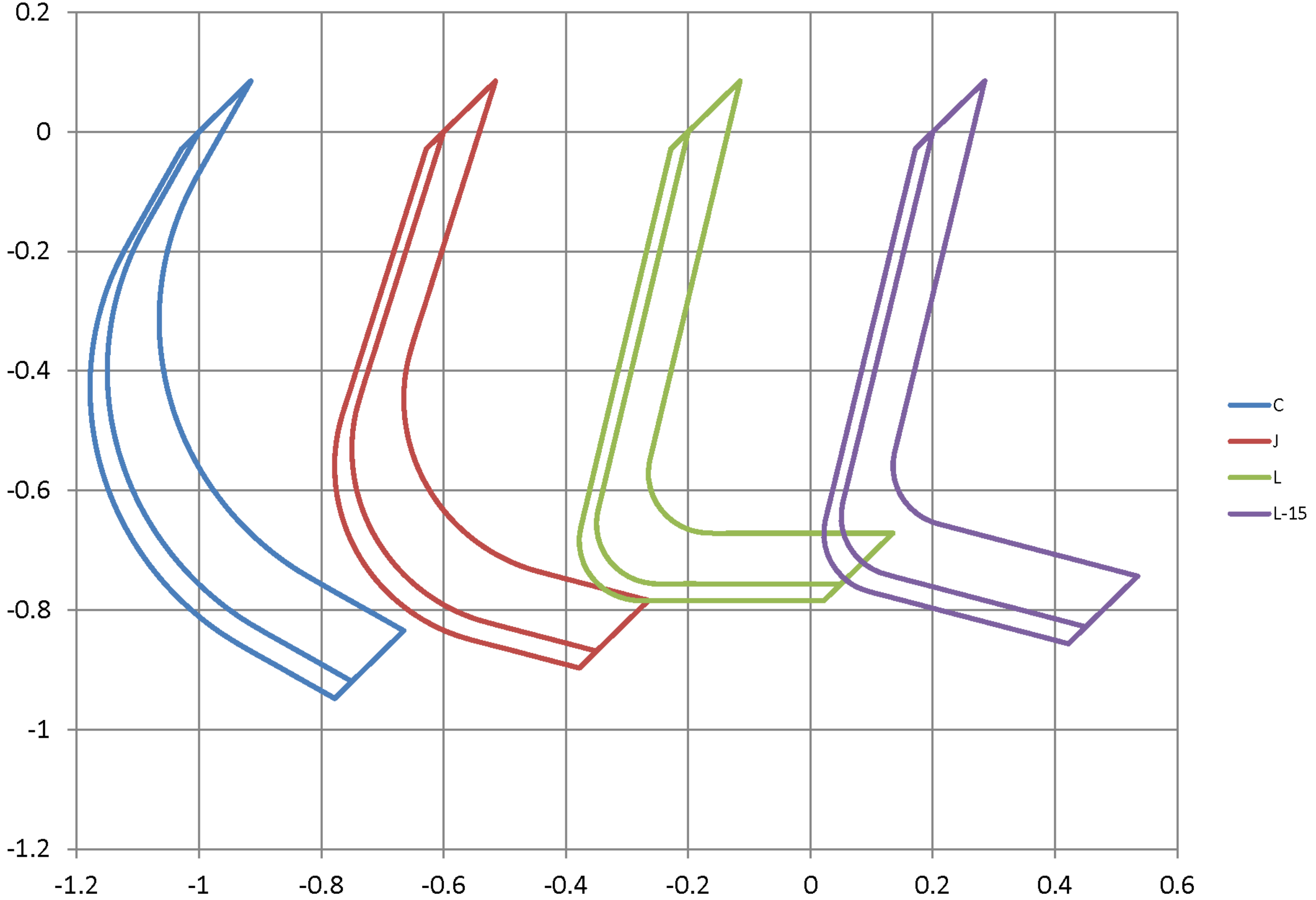
Ideas For The Future

Problem of Symmetry

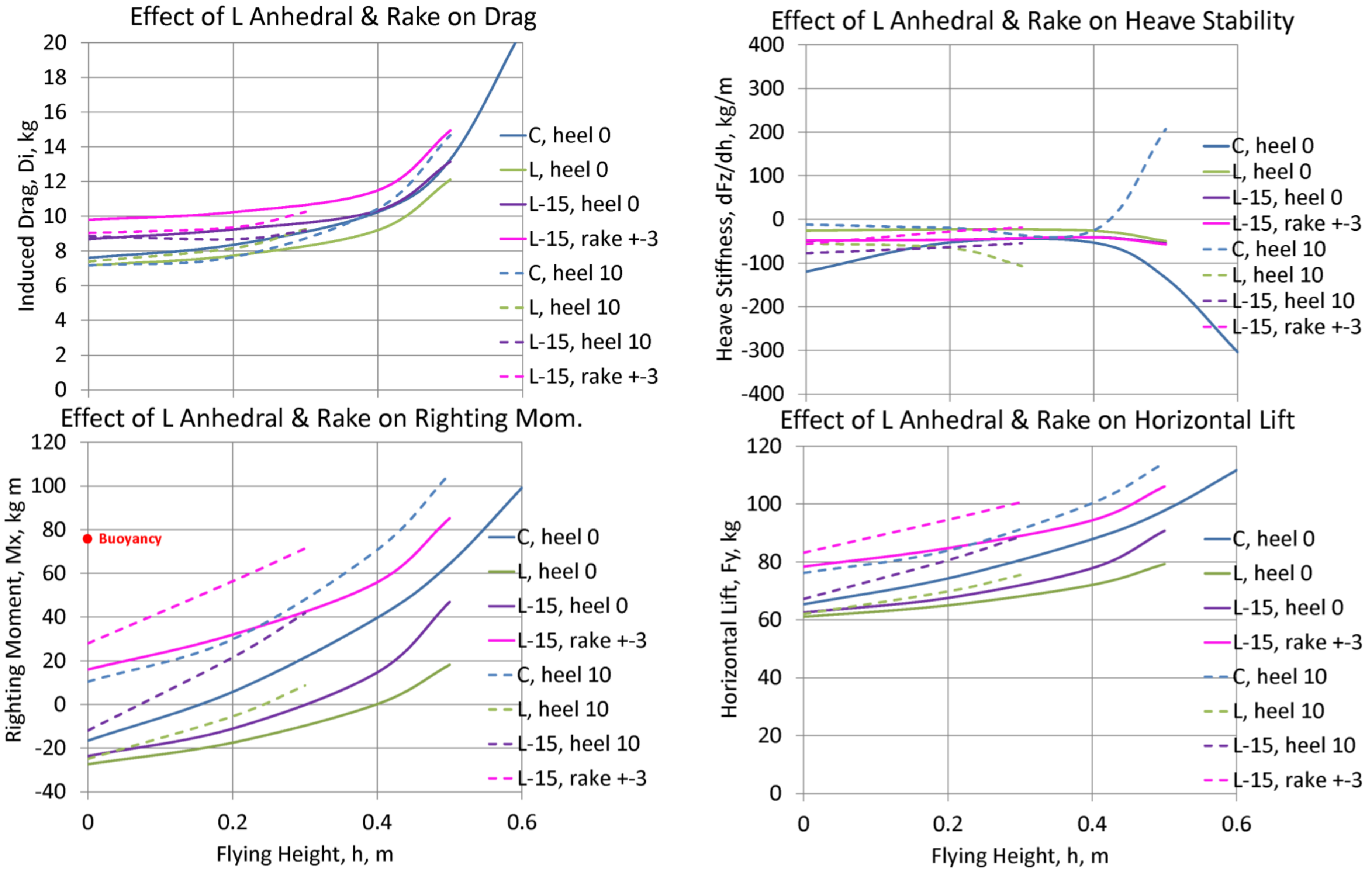


- Angle of attack affects both boards equally
- Equal vertical lift has no righting moment
- *Need to rake boards differentially*

L Foil With Anhedral

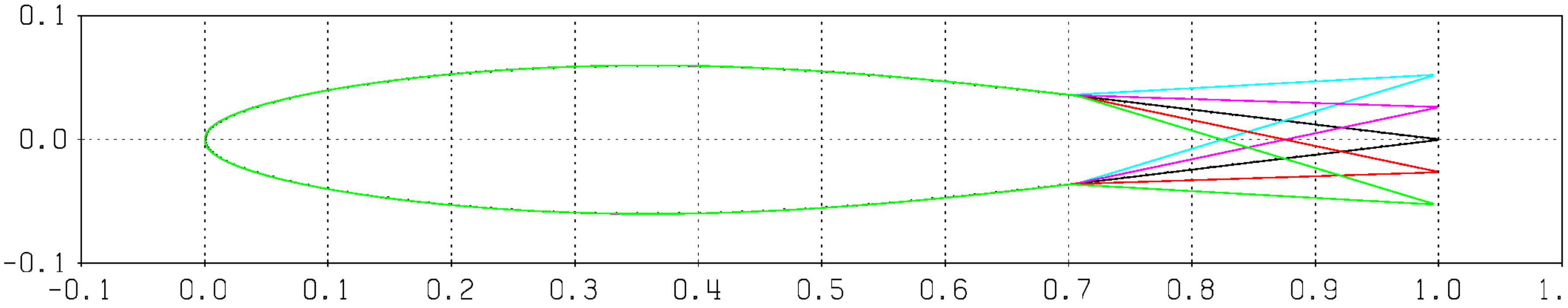


Effect of Differential Rake

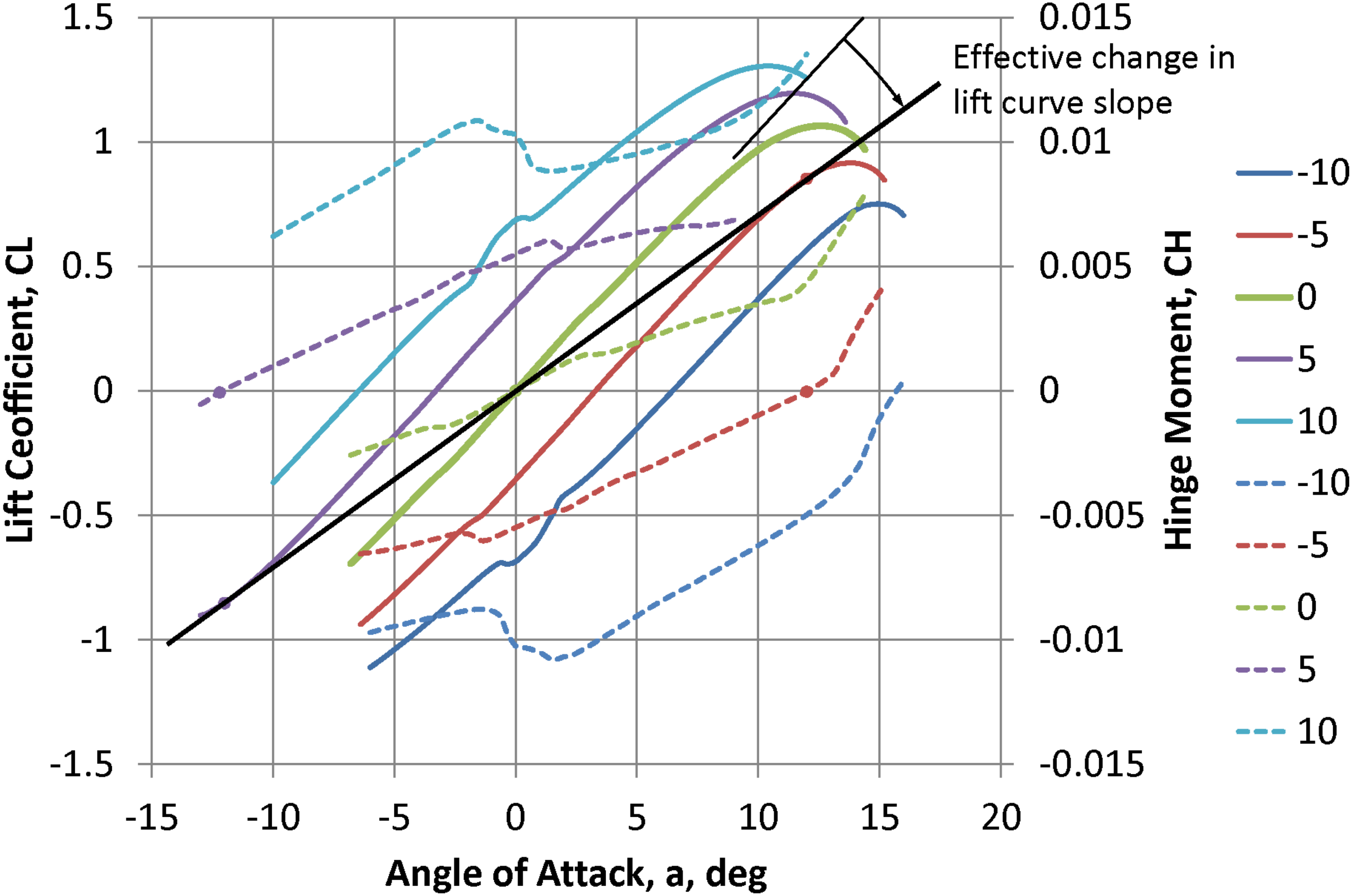


Floating Flap

- Flap hinge moment is function of:
  - Flap shape (trailing edge camber)
  - Flap deflection
  - Angle of attack
- Flap free => hinge moment = 0
- Negative flap deflection reduces lift



NACA 63012a With 30% Chord Flap



Fine