A Comparative Study of Program FloSim Results Against SYRF Wide Light Project Data

Brian Maskew and Frank DeBord
Acknowledgements

• We greatly appreciate the efforts of the Sailing Yacht Research Foundation to encourage open sharing of the valuable data published from the Wide Light Project.

• This has provided a rare opportunity for CFD code validation and we sincerely thank the Foundation sponsors, leadership and Technical committee for that.
Overview of Presentation

- Outline of SYRF Wide-Light Project
- FloSim Program—Background, Objectives, Ingredients
- Wide-Light Model Description & Test Matrix
- Computer Model Arrangement
- Comparison of Calculated and Test Results
- Computer Requirements & Run Times
- Conclusions and Further Work
SYRF Wide Light Project

• **Sailing Yacht Research Foundation:**
  - Their mission concerns sailing yacht performance and handicapping
  - They conceived & sponsored the Wide Light Project in 2013

• **Wide Light Project Objectives**
  - Expand the yacht hydrodynamic public database to include modern yachts; the existing data base being out-of-date
  - Procure a tank test model of a contemporary racing yacht
  - Conduct a tank test; this was carried out by the Wolfson unit in a QuinetiQ towing tank, Gosport, UK
SYRF Wide Light Project, concluded

• **A Comprehensive Test Matrix:**
  - Canoe body and appended configurations
  - Upright and heeled conditions,
  - Ranges of speed, yaw, rudder deflection and CG location

• **CFD Practitioners** were invited to perform “blind” analyses of the Wide Light model over the full test matrix:
  - These results were delivered *prior* to the tank tests
  - On average the Star-CCM+ RANS code results were closest to the tank data and are included here in our data comparisons

• **The Project Results** were presented in 2016 at the 22nd CSYS by Martin Prince and Andrew Claughton
Program FloSim

• FloSim is a relatively new computer program

• It has had little exposure in public presentations so is probably not widely known

• In fact, FloSim has been used in a number of projects but these have been mainly proprietary (AC, Volvo, etc.) so results were tightly held

• Hence, as way of introduction, and to establish some degree of credibility, FloSim’s background is outlined on the next slide
Program FloSim Background

• Program **QuadVort**: 1961 to 1974;
  ➢ Doublet panel code
  ➢ Non-linear vortex wake
  ➢ High lift wing and wing-body configurations

• Program **VSAERO**: 1975-1985;
  ➢ Doublet and source panel code
  ➢ Coupled Boundary Layer Analysis
  ➢ Steady conditions for aircraft, submarines, etc.

• Program **USAERO**: 1985-2003;
  ➢ Unsteady version of VSAERO; aircraft, helicopters, high speed trains
  ➢ 6 DOF motion solver module; submarine maneuver and store release
  ➢ Non-linear free surface module; surface ships and racing yachts

• Program **FloSim**: 2003 to present;
  ➢ Essentially a rewrite of USAERO in Fortran 90 for Windows PC
  ➢ Improved routines for geometry, free surface, vortex wake, matrix solver
  ➢ Primarily aimed at sailing yacht hydrodynamics & sail aero/structural analysis
Program FloSim Development Objectives

FloSim

RANS

Potential Flow Method

“Real-Flow” Accuracy

Ease of Use

Computer Resources & Turnaround Time

Better

Better

Better

FloSim

FloSim

FloSim

RANS

PFM

RANS

PFM

RANS

PFM

Brian Maskew and Frank DeBord  23rd CSYS
Objectives of this Paper

- Validate Program FloSim Results (Given the rare opportunity offered by the SYRF Wide Light data)

- Examine to what extent FloSim’s development objectives are being achieved:
  - Prediction accuracy leaning towards the “real-flow” accuracy of RANS
  - Simple computer resource requirement
  - Rapid solution time for quick turnaround
Program FloSim
An Advanced Boundary Element Method
Ingredients:

- Non-Linear Vortex-Wake Model
- Boundary Layer Analysis
- Separated Flow & Bubble Model
- Non-Linear Free-Surface Method
- Wave-Breaker Model

Unsteady Potential Flow Panel Method
Program FloSim
Outline of Ingredients

• Non linear Vortex wake: treats large scale vortical flow separations such as at wing tips and lee-side body vortices

• Coupled Integral Boundary layer Method; computes skin friction drag & boundary layer displacement effect; Boundary layer analysis proceeds from laminar flow through transition to turbulent flow

• Extensive Flow Separations; modeled using vortex sheets to represent separated shear layers

• Non linear Free Surface treatment; uses mixed Eulerian/Lagrangian approach of Longuet-Higgins and Cokelet, 1976.

• Wave-Breaker Module; this is a key ingredient for the current project here and since it has not been presented elsewhere a few slides are given below to describe it and to demonstrate its capabilities.
FloSim’s Wave-Breaker Model

Consider a Breaking Wave Profile
e.g., for a planing hull

- The wave crest formation, breaking and jet development can be captured in 2D simulations using a very high panel density

- For 3D Simulations:
  - Such high panel density would be too time consuming
  - Practical panel densities cannot resolve the crest details
  - A rounded wave crest may form having excessive amplitude
  - Hence, trim, heave and resistance predictions may suffer
  - A wave-breaker model is therefore needed to convert energy
FloSim’s Wave-Breaker Model, cont’d

Free Surface Eqn: \[ \frac{\partial \phi}{\partial t} = gz + \frac{1}{2} v^2 + \frac{\Delta p}{\rho} \]

where \[ \frac{\Delta p(x)}{\rho} = g \times D_f \times h(x) \]

Foamy Region Height: \[ H = H_f \times z_{crest} \]

Empirical Parameters:
- Foam Density Factor: \[ D_f = 0.2 \text{ to } 0.6 \] (Tulin)
- Foam Height Factor: \[ H_f = 1.28 \] (Muscari)
- Critical Slope Angle: \[ \theta_{crit} = 15^\circ \] (Duncan)
FloSim’s Wave-Breaker Model, cont’d
Duncan’s Hydrofoil-in-Tank Experiment Layout
Particular Conditions for *Non-Spontaneous* Breaking

- Hydrofoil Frame: offset $X_p = \text{chord}/2$ and rotated about its $y$-axis
- Depth below Free Surface: $d = 0.193\text{m}$, $d/c = 0.961$
- Foil height above Tank Bottom: 0.175m
- Hydrofoil chord; $c = 0.203\text{m}$
  - $t/c = 0.125$
  - Section NACA 4-Digit
  - Speed $= 0.801 \text{ m/sec}$
  - $F_n = 0.568$
FloSim’s Wave-Breaker Model, cont’d

General Views of the Calculated Waves at 0.193m Submergence; Particular Condition for Non-Spontaneous Breaking

Wave contours just before applying the Breaker Model

Upper Tank Walls Removed for Clarity

Foil and Wake

\[ \frac{\Delta p}{\rho} \] distribution just after applying the Breaker Model (each crest is beyond \( \theta_{\text{crit}} \))
FloSim’s Wave-Breaker Model, cont’d

General Views of the Calculated Waves at 0.193m Submergence; Particular Condition for non-Spontaneous Breaking. End of Run

All crests now at reduced height

Note: Scales are same as in previous slide

Wave Contours at end of run with Breaker Model active

Δp/ρ now applied only at first crest; Only the first crest has θ > θ_{crit}
FloSim’s Wave-Breaker Model, cont’d

Calculated Free Surface Elevation History at first Trough & Crest

Submergence Depth: ... 0.193m ; depth/c = 0.9507
Speed: .................. 0.81m/sec; \( F_n = 0.568 \)
Alpha: .................... 5.0 deg

First Crest

Disturbance applied very gradually

Amplitude reduction

Breaker Model Off

First Trough

Breaker Model Active

Small change in trough depth
FloSim’s Wave-Breaker Model, cont’d

Duncan’s Hydrofoil Experiment with \( d = 0.193 \text{m} \)

Calculated Particle Energy Coefficient History

Energy loss in breaker; Mainly in potential energy but also drop in the wave orbital velocity magnitudes

Breaker “ON” at \( t = 7.96 \text{ sec} \)

Kinetic energy peaks before crest
FloSim’s Wave-Breaker Model, cont’d
Duncan’s Hydrofoil Experiment with d=0.193m
Comparison of Calculated and Measured Wave Profiles
(a) Initial Non-Breaking Condition

FloSim Exp.
Muscari

(possible influence from downstream buffer zone)
FloSim’s Wave-Breaker Model, cont’d
Duncan’s Hydrofoil Experiment with d=0.193m
Comparison of Calculated and Measured Wave Profiles
(b) Breaking Condition

![Graph showing comparison of calculated and measured wave profiles.](image)

- Free Surface Elevation, Z m
- Distance, X m

FloSim
Muscari
Exp.

(Exp. Crest Height before breaking)
(Exp. Trough Depth before breaking)
(possible influence from downstream buffer zone)
FloSim’s Wave-Breaker Model, cont’d
Model Parameters for the Breaking Bow Wave

• For general case, basic strategy of monitoring particle energy still applies
• Parameters based on Duncan’s 2D experimental data may need to be modified for 3D conditions in the breaking bow wave in the current project.

• Foam Height Factor, $H_f$
  ➢ The value of 1.28 (Muscari) seemed too big for Duncan’s experimental data, but in any case, without a forward trough, the value must be less than 1.0.
  ➢ For now use $H_f = 0.8$

• Critical Slope Parameter, $\theta_{\text{crit}}$
  ➢ 15° worked for Duncan’s 2D experiment but here the crest is swept back.
  ➢ Here, tank test photos indicate breaking had already started by $F_n = 0.35$.
  ➢ Examining particle traces in the flow approaching the bow wave crest we found their trajectory slope reached just above 10° at this speed
  ➢ For now set $\theta_{\text{crit}} = 10^\circ$ to activate the Breaker Treatment at $F_n = 0.35$ and above
FloSim’s Wave-Breaker Model, concluded

Model Parameters for the Breaking Bow Wave

- Foam Density Factor, $D_f$
  - $D_f = 0.5$, used for Duncan’s experiment, was used here for initial calculations and seemed to work well up to about $F_n = 0.55$.
  - Above $F_n = 0.55$, trim and heave departures from the measured data indicated more energy needs to be extracted from the bow wave, i.e., a higher $D_f$ needed.
  - Considering the $F_n = 0.8$ point in the SYRF data, we tried higher $D_f$ values; but no single $D_f$ value found that gave both trim and heave data matches.
  - This implies the locations for the downstream trough and peak are slightly off; changes to $H_f$ and possibly the shape of the $\Delta p$ distribution need to be tried but this would be “hit-and-miss” without wave profile measurements.
  - $D_f = 0.9$ gave a reasonable compromise solution for trim & heave at $F_n=0.8$.
  - We used a quadratic curve to link $D_f = 0.9$ at $F_n=0.8$ to the 0.5 value at low $F_n$.
  - Cases between $F_n$ 0.55 and 0.8 used interpolated $D_f$ values from that curve.

Brian Maskew and Frank DeBord  23rd CSYS
SYRF Wide Light Model

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Length, L</td>
<td>4.88 m</td>
<td>(16 ft)</td>
</tr>
<tr>
<td>Design LWL</td>
<td>4.60 m</td>
<td>(15 ft)</td>
</tr>
<tr>
<td>Displacement: canoe body appended</td>
<td>197 kg</td>
<td>(434 lb)</td>
</tr>
<tr>
<td></td>
<td>215 kg</td>
<td>(473 lb)</td>
</tr>
<tr>
<td>Maximum Beam</td>
<td>1.28 m</td>
<td>(4.2 ft)</td>
</tr>
<tr>
<td>Draft to Datum</td>
<td>1.15 m</td>
<td>(3.8 ft)</td>
</tr>
</tbody>
</table>

Boundary Layer “Transition Strips”:
- On hull at 0.3m from bow; 6% L
- On keelfin and rudder at 0.25% chord
- On bulb at 20% length

Test Froude Number Range: 0.1 to 0.8
Test Reynolds Number Range: 3 to 24 million (based on L)
## SYRF Test Matrix
### Canoe Body Configuration

<table>
<thead>
<tr>
<th>ID</th>
<th>Runs</th>
<th>Test</th>
<th>Fn</th>
<th>Heel</th>
<th>Yaw</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB-1</td>
<td>001-015</td>
<td>Upright Resistance</td>
<td>0.1 to 0.8*</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CB-2</td>
<td>016-020</td>
<td>LCG Variation*</td>
<td>0.35</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CB-3</td>
<td>021-025</td>
<td>LCG Variation</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CB-4</td>
<td>026-030</td>
<td>Heel at Zero Yaw</td>
<td>0.25 to 0.45</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>CB-5</td>
<td>031-035</td>
<td>Heel at Zero Yaw</td>
<td>0.25 to 0.45</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>CB-6</td>
<td>036-040</td>
<td>Heel with Yaw</td>
<td>0.35</td>
<td>15</td>
<td>-2 to 3</td>
</tr>
<tr>
<td>CB-7</td>
<td>041-045</td>
<td>Heel with Yaw</td>
<td>0.5</td>
<td>25</td>
<td>-2 to 3</td>
</tr>
</tbody>
</table>

# To represent moment due to sail force, CG was moved forward as speed increased:
LCG moved from 2.488 m from bow at Fn 0.1 to 2.127 m at Fn 0.8  (LCG / L ≈ 0.51 to 0.44)

* LCG range 2.784 m from bow to 2.184 m  (LCG / L ≈ 0.57 to 0.45)
### SYRF Test Matrix, concluded

**Appended Configuration; Hull, Keel, Rudder**

<table>
<thead>
<tr>
<th>ID</th>
<th>Runs</th>
<th>Test</th>
<th>Fn</th>
<th>Heel</th>
<th>Yaw</th>
<th>Rudder</th>
</tr>
</thead>
<tbody>
<tr>
<td>HKR-1</td>
<td>046-060</td>
<td>Upright Resistance</td>
<td>0.1 to 0.8</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HKR-2</td>
<td>061-065</td>
<td>LCG Variation</td>
<td>0.35</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HKR-3</td>
<td>066-070</td>
<td>LCG Variation</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HKR-4</td>
<td>071-075</td>
<td>Heel at Zero Yaw</td>
<td>0.25 to 0.45</td>
<td>15</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HKR-5</td>
<td>076-080</td>
<td>Heel at Zero Yaw</td>
<td>0.25 to 0.45</td>
<td>25</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HKR-6</td>
<td>081-085</td>
<td>Heel with Yaw</td>
<td>0.35</td>
<td>15</td>
<td>-2 to 3</td>
<td>0</td>
</tr>
<tr>
<td>HKR-7</td>
<td>086-090</td>
<td>Heel with Yaw</td>
<td>0.5</td>
<td>25</td>
<td>-2 to 3</td>
<td>0</td>
</tr>
<tr>
<td>HKR-8</td>
<td>091-095</td>
<td>Yaw sweep, Rudder Variation</td>
<td>0.35</td>
<td>15</td>
<td>1, 3, 5</td>
<td>0, 2, 4</td>
</tr>
<tr>
<td>HKR-9</td>
<td>096-100</td>
<td>Yaw sweep, Rudder Variation</td>
<td>0.5</td>
<td>15</td>
<td>0, 2, 4</td>
<td>0, 2, 4</td>
</tr>
<tr>
<td>HKR-10</td>
<td>101-105</td>
<td>Yaw sweep, Rudder Variation</td>
<td>0.35</td>
<td>25</td>
<td>1, 3, 5</td>
<td>1, 3, 5</td>
</tr>
<tr>
<td>HKR-11</td>
<td>106-110</td>
<td>Yaw sweep, Rudder Variation</td>
<td>0.5</td>
<td>25</td>
<td>0, 2, 4</td>
<td>1, 3, 5</td>
</tr>
</tbody>
</table>
Computer Model Details
Considerations for Panel Grid Size

• Hull Grid:
  ➢ Generally use at least 50 panels along hull length, \( L = 4.88 \text{m} \) here; hence, basic panel x interval, \( \Delta x = 4.88/50 \approx 0.1 \text{m} \)
  ➢ Use this as preliminary *distance moved* in one time step:
    i.e., \( \text{DxMove} = 0.1 \text{m} \), but check the wavelength:
  ➢ For stable wave analysis use at least 20 *intervals* in one wavelength:
    i.e., \( \Delta x = \lambda / 20 \) where \( \lambda = 2\pi V^2 / g \)  
    (Note: typo in paper)
  ➢ With \( \text{DxMove} = 0.1 \text{m} \) we have critical wavelength, \( \lambda_c = 20 \times 0.1 = 2 \text{ m} \)
  ➢ This corresponds to a critical Froude Number, \( \text{Fn} = 0.26 \)
    (issues for speeds below \( \text{Fn} = 0.26 \) are considered on a later slide)

• Free Surface Grid:
  ➢ Automatically set up by the program using the same \( \Delta x \) spacing as on the hull
Computer Model Details, cont’d
Hull Grid

Transom Patch (inactive)

Main Hull Patch

Current Waterline
Automatic Hull/Free Surface Intersection and regridding procedure

Longitudinal grid: 55
(49 for canoe body case)

Lateral grid: 16 on Starboard Half
(6 remain “dry” above waterline)

Extra panels covering appendage junction areas

Junction insert patches (see detail on next slide)
Computer Model Details, cont’d
Keelfin and Rudder Grids

Rudder

- Insert Patch at Rudder/Hull Junction
- Chordwise (stbd half): 30 (dense towards LE)
- Spanwise: 10 (small at root and tip)

Keelfin

- Insert Patch at Keelfin/Hull Junction
- Buffer zone for transition between dense grid on appendage and relatively less dense hull grid
- Chordwise (stbd half): 30 (dense towards LE)
- Spanwise: 10 (small at root and tip)

Note: Isometric Views of Stbd half
Computer Model Details, cont’d

Bulb Grid

Lateral grid (stbd half):
3 across Upper patch

Bulb Upper Patch

Lateral grid (stbd half):
17 across Lower patch

Bulb Lower Patch

Longitudinal grid: 40
(dense towards Nose and
Fin Junction)

Bulb Upper Patch

Detail of Junction Patch

Bulb Lower Patch

Keel fin

Junction grid distortion
confined to Upper Patch

Note: Isometric View of Stbd half
Computer Model Details, concluded

Free Surface Grid

<table>
<thead>
<tr>
<th>Total Panel Count</th>
<th>Hull</th>
<th>1,760</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keel fin</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>Rudder</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>Bulb</td>
<td>1,600</td>
<td></td>
</tr>
<tr>
<td>Free Surface</td>
<td>8,280</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>12,840</td>
<td></td>
</tr>
</tbody>
</table>

Length of downstream part depends on amount of wave pattern needed

Note: Free Surface size and grid density increased for $\text{Fn} < 0.26$
Computer Model Details
Special Considerations

• Low Fn issues below \( Fn = 0.26 \) need special treatment:
  ➢ **Reduce DxMove** to keep at least 20 steps/wavelength (needs new panel grid)
    
    Here; \( DxMove = 0.05 \) for \( Fn 0.25 \) and \( 0.2 \);
    
    \( DxMove = 0.03 \) for \( Fn 0.15 \) and \( 0.1 \)

  ➢ **Transient wave problems resulting from impulsive start:**
    
    o More time steps needed, say 600; (200 - 400 OK at higher speeds)
    
    o Apply disturbance *very* gradually using “Sieve” treatment;
      
      Body *Porosity* varies from 1 to 0 over the sieve period (~ 400 steps)
    
    o Apply wave damping “beaches” along outer edges of free surface patches;
      
      beach width \( \cong \) wavelength, \( \lambda \)
SYRF Wide Light Data Issues

• Laminar Flow Resistance “Correction”
  ➢ The tank resistance data was “corrected” for the laminar flow ahead of boundary layer transition strips, i.e., changed to fully turbulent conditions.
  ➢ FloSim resistance has laminar flow contribution from those forward areas
  ➢ We were unable to obtain the actual test correction values so added code to FloSim to compute and display what that value might be, and used that to adjust the FloSim resistance data: the procedure:
    o Extract the laminar flow resistance contribution, \(D_L\), for hull, bulb, etc.
    o For each calculated streamline, extract a turbulence factor, \(F_T\), for the ratio:
      \[
      \frac{\text{Turbulent skin friction coefficient}}{\text{Laminar skin friction coefficient}}
      \]
      across the transition zone
    o get an average \(F_T\) ratio for the hull and for each appendage
    o The calculated resistance increment for each part is then \((F_T - 1) \times D_L\)
      (typo in paper)
• Laminar Flow Separation on Fin and Rudder
  
  ➢ In these tests the Reynolds Number based on chord for the keel fin and rudder is in the range 33,000 to 263,000
  
  ➢ this is in the range where complex force and moment characteristics can occur due to laminar long bubble separations.
  
  ➢ FloSim’s treatment of these is incomplete, so, when needed for a particular appendage, (i.e., to suppress extensive laminar separation) we applied an artificial kinematic viscosity on that appendage to maintain $Rn_c > 500,000$
Example Plots from FloViz
Calculated Hydrodynamic Force and Moment Histories
Heel 25°, Yaw -2°, Fn 0.5

Essentially converged by Step 120
(lower speeds generally need more steps)

Solution (every 4th step)
Example Plots from FloViz
Close Up View at Fn 0.5 with Heel 25°, Yaw -2°
Showing Computed Streamlines & Wave Contours

*Disturbance from keelfin circulation*

*Top of rudder just out of water*

*Computed streamlines*
Results for Upright Condition
Comparison of Trim versus Speed

Canoe Body

Appended
Results for Upright Condition, cont’d
Comparison of Heave versus Speed

Canoe Body

Appended
Results for Upright Condition, cont’d
Comparison of Resistance versus Speed

![Graph showing comparison of resistance versus speed for different models and simulations.](image)

- Tank CB1
- FloSim CB1
- Star-CCM+ CB1
- Tank HKR1
- FloSim HKR1
- Star-CCM+ HKR1

Canoe Body
Appended

Errors:
- 2%
- 5%
- 10%
- 12%

Resistance (N) vs. Fn
Results for Upright Condition, cont’d

Appended Configuration

Comparison of Trim versus LCG Position

![Graph showing comparison of Trim versus LCG Position]
Results for Upright Condition, cont’d

Appended Configuration

Comparison of Heave versus LCG Position

![Graph showing comparison of heave versus LCG position for different configurations.]

- Tank HKR2
- FloSim HKR2
- Star-CCM+ HKR2
- Tank HKR3
- FloSim HKR3
- Star-CCM+ HKR3

LCG (m) vs. Heave (m)

- LCG 0.448 L
- LCG 0.57 L

Heave values for different Fn:
- Fn = 0.35
- Fn = 0.5

CG Moving aft
Results for Upright Condition, concluded

Appended Configuration

Comparison of Resistance versus LCG Position

Errors
- 3%
- 11%
- 10%

Resistance (N)

LCG (m)

- Tank HKR2
- FloSim HKR2
- Star-CCM+ HKR2
- Tank HKR3
- FloSim HKR3
- Star-CCM+ HKR3

Error 4%

Fn = 0.5
Fn = 0.35

LCG 0.57 L
CG Moving aft
LCG 0.448 L
Results with Heel at Zero Yaw
Appended Configuration
Comparison of Trim versus Speed at Heel 25°
Results with Heel at Zero Yaw, cont’d

Appended Configuration

Comparison of Heave versus Speed at Heel = 25°
Results with Heel at Zero Yaw, concluded

Appended Configuration

Comparison of Resistance versus Speed at Heel=25°
Results with Heel and Yaw Appended Configuration

Comparison of Resistance versus Yaw

Heel = 25°, F_n = 0.5

Heel = 15°, F_n = 0.35
Results with Heel and Yaw, concluded

Appended Configuration

Comparison of Side Force versus Yaw

- Tank HKR6
- FloSim HKR6
- Star-CCM+ HKR6
- Tank HKR7
- FloSim HKR7
- Star-CCM+ HKR7

Heel = 25°, Fn = 0.5
Heel = 15°, Fn = 0.35

Yaw (deg)
Results with Rudder Deflection
Appended Configuration in Heel & Yaw
Comparison of Resistance versus Rudder Deflection

Heel = 25°

Fn = 0.5, Yaw = 2°
Fn = 0.35, Yaw = 3°
Results with Rudder Deflection, concluded

Appended Configuration in Heel & Yaw

Comparison of Side Force versus Rudder Deflection

Yaw = 3°, Fn = 0.35

Heel = 15°, error ~17%

Heel = 25°
## Computer Requirements

<table>
<thead>
<tr>
<th></th>
<th>FloSim</th>
<th>Star-CCM+</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Computer</strong></td>
<td>13” HP Spectre Laptop</td>
<td>Computer Cluster</td>
</tr>
<tr>
<td></td>
<td>Intel i7-7500 CPU (7th gen)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.7 GHz</td>
<td></td>
</tr>
<tr>
<td><strong>Cores</strong></td>
<td>2 (i.e. 2 cases simultaneously)</td>
<td>16</td>
</tr>
<tr>
<td><strong>Memory</strong></td>
<td>16 GB</td>
<td></td>
</tr>
<tr>
<td><strong>Hard Drive</strong></td>
<td>700 GB</td>
<td></td>
</tr>
</tbody>
</table>

### Configuration

<table>
<thead>
<tr>
<th>Configuration</th>
<th>FloSim</th>
<th>Star-CCM+</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Condition</td>
<td>Hours/Case</td>
</tr>
<tr>
<td>Canoe Body</td>
<td>Symmetrical</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Asymmetrical</td>
<td>1.0</td>
</tr>
<tr>
<td>Appended</td>
<td>Symmetrical</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Asymmetrical</td>
<td>2.0</td>
</tr>
</tbody>
</table>
Conclusions

• The results show the primary objectives of the paper have been essentially achieved:
  ➢ FloSim calculations are validated here against measured data with accuracy approaching that of RANS.
  ➢ The aims for simple computer requirement and rapid case turnaround have been fulfilled.
  ➢ These things are useful for rapid evaluation of:
    o handicap rules for racing boats
    o multiple design options for a new boat
• The Wave-Breaker Model is a key ingredient for the higher speed results but further refinement is possible
Further Work

• Possible further refinement of the Wave-Breaker Model:
  ➢ Refine the Wave-Breaker empirical parameters using data from a variety of configurations and range of conditions where available.
  ➢ Look for data that include wave profile measurements, ideally with velocity distributions
  ➢ Reconsider the form of the $\Delta p$ distribution
  ➢ Use particle energy rather than $F_n$ for $D_f$ variation basis

• FloSim’s model for long bubble separations needs to be completed for improved treatment of tank test model appendages operating at low Reynolds Numbers
Thank You for Your Attention
The Following are Supplementary Slides not shown due to lack of time
FloSim Calculation for Rectangular Plate;

A=0.25  (Re: Experiment by Wickens, R.H., 1967)
$C_L, C_D \sim$ Alpha for a Rectangular Plate; 
Aspect ratio=0.25

$C_L \sim$ Alpha

$C_D \sim$ Alpha

Measured (Whickens)
Calculated (FloSim)
Linear Wake Calc.
FloSim Boundary Layer Method

• Laminar Method
  - Laminar Separation > transition > turbulent reattachment (i.e., short bubble)
  - Laminar Separation

• Transition to Turbulent Flow
  - Free Transition (empirical stability criteria)
  - Forced Transition:
    o provide transition strip location, or
    o specify “as soon as possible” (momentum thickness Rn criterion)

• Turbulent Method
  - Turbulent Separation
    o Skin friction coefficient, Csf, criterion, or
    o Shape Factor, H, criterion
FloSim Boundary Layer Effects

(a) Attached Flow

- Surface Skin Friction Drag (Upper and Lower Surfaces)
- Displacement Effect Reduces Effective Camber
- Effective Displacement Boundary (Exaggerated)
- Boundary Layer Displacement Source Distribution on Lower & Upper Surfaces
- Wake Sink Entrainment Distribution is Superimposed on Vortex Wake

V_A

Sail Membrane
FloSim Boundary Layer Effects cont’d

(b) Separated Flow

- Computed B/L Separation
- Effective Camber is Reduced even further
- Effective Displacement Boundary
- Computed Bubble Separation/Reattachment
- Near Wake Sink Distribution
- Separated Source Distribution

$V_A$

Sail Membrane
FloSim Boundary Layer Effects, cont’d
(c) Long Bubble Separation Options

(i) Source Model

Bubble Boundary
Source Sink

γ = constant

(ii) Vortex Sheet Model

Reattachment
Sail Membrane
FloSim Boundary Layer Effects cont’d
Sail-Mast Example;
Computed Boundary Layer Status

Sail : Aspect Ratio, \( A_e \) = 20
Camber, \( f/c \) = 0.125
Alpha = 15°
\( Rn \) = 1 mil
Mast: diameter/c = 0.1

Blstat:
0 = Laminar
1 = Turbulent
2 = Bubble Separation
3 = “TE” Separation

Brian Maskew and Frank DeBord 23rd CSYS
FloSim Boundary Layer Effects, concluded
Bluff-Body Separation Model Options

(i) Source Outflow Model
- Base Cp ≈ 0
- External Streamlines
- Onset Flow

(ii) Vortex Sheet Model
- Wake V (≈ 0) & Base Cp are part of solution

Simple Potential Flow Model has stagnation Cp in the Base

Brian Maskew and Frank DeBord  23rd CSYS