AUVSIM · METHOD NOTE

AUV hull shape search: method and validation.

The shape search finds a hull, internal layout and pressure housing that trade drag against dry mass for a given set of components and rules. This note sets out how it works, which hull shapes it covers and how far each is validated, and what hulls with a flat bottom or a keel would need.

HOW THE SEARCH WORKS

Place, balance, wrap, score.

For each candidate, the search places the components (order, slot and axis), solves buoyancy packs and a lead trim weight so the vehicle trims exactly, wraps the smallest hull around them, and scores the result. Layouts that break a rule rank below those that don't. With two objectives, drag and dry mass, it runs NSGA-II and returns a Pareto front for each housing material, then merges the fronts.

What the search can change

- Part order, slots and axis; buoyancy packs and a solved trim weight; rule-based ranking
- The hull skin: the smallest elliptic or rounded-rectangle section around the components, with Myring nose and tail profiles
- Nose exponent, tail angle, nose and tail lengths, and fin area, under a yaw-stability floor ($G \geq 0.2$)
- Pressure housings: material and end caps, sized for the design depth
- The hull's position along the vehicle, for weight and balance
- Capsule components, with mass from density or specific gravity

Hull added mass comes from strip theory for slender hulls, and from a boundary-element (BEM) solver, Capytaine, for short or boxy hulls.

What the results usually show

Drag and mass barely trade off. The housing sets the mass and the hull shape sets the drag, so the best choice of housing tends to win on both. In our reference study, aluminium with hemispherical end caps beat titanium and flat caps on both objectives.

An optimum on a limit is flagged, not trusted. The drag model has no flow separation, so on its own it would reward a full nose and a steep tail without limit; a 20° tail-slope rule holds it back. When a result sits on that rule or at the top of the nose-exponent range, its proportions need a CFD check before anyone builds from them.

HULL SHAPES COVERED

Where the model is trustworthy, and where it isn't.

The model is trustworthy for slender, round, gently tapered hulls like DARPA SUBOFF. Confidence drops for flattened, boxy or short hulls, and for full noses and steep tails. Every hull it describes today is symmetric about both long planes: an ellipse or a rounded rectangle, centred on the axis, scaled along the length by the nose and tail profiles.

Shape	Added mass	Drag and lift	Confidence
Slender body of revolution, L/D about 6 to 9, gradual tail (SUBOFF-like)	Strip theory within 4 % of exact; BEM within 3.7 %	Deep axial drag of SUBOFF within about 10 %; side force and moment derivatives within 10–15 % of Roddy (1990)	High
Slender elliptic section, 2:1 to 3:1	Strip within 4 % (2:1); surge +9 % and yaw +12 % (3:1); BEM within 3.7 %	Same formulas as round hulls, using the equal-area diameter; not yet checked on a flattened hull	Medium
Rounded-rectangle (boxy) section	Strip 0.25–0.76× BEM in pitch and yaw; BEM used	Cross-flow drag from 2-D rectangle tables; flat-face nose drag a rough estimate; not yet checked	Low to medium
Short or wide hull (L/D under about 4)	Strip off by −51 % in pitch on a short, wide ellipsoid; BEM used	Lift calibrated on one slender hull only; an estimate	Low
Full nose (Myring n 3 to 4) or tail steeper than about 20°	Unaffected	No flow separation in the drag model; held back by the 20° tail-slope rule	Low for drag; CFD check before use
Top/bottom asymmetric (flat bottom, D-section, keel unlike crown)	Not yet described	Not yet described	Not covered yet

Near the surface, wave drag and total resistance are within about 15 % at a depth of at least one hull diameter, checked on round hulls only. Pressure housings are rated by the EN 13445-3 collapse curve, at least 1.70× below every one of 36 published collapse tests (Windenburg & Trilling, 1934). Each comparison is kept with a raw run and a script that reproduces it.

HULLS WITH A FLAT BOTTOM OR KEEL

What asymmetric hulls need.

Keeping port/starboard symmetry but letting the top and bottom differ touches eight parts of the model. The biggest is lift: such a hull is effectively cambered. It makes lift and a pitching moment at zero incidence, must fly at an angle of attack to stay level, and pays induced drag for it.

Area	For symmetric hulls	For asymmetric hulls
Section geometry	One half-width and one half-height, centred on the axis	One half-width plus separate upper and lower halves, each with its own height and shape; separate crown and keel profiles along the length
Hull skin	Every component mirrored top to bottom, so a low part costs its mirror image above; one envelope and one Myring fit	Separate upper and lower envelopes and fits; an option for a straight (flat) keel line; new search variables for upper and lower aspect, lower shape and keel shape

Area	For symmetric hulls	For asymmetric hulls
Mass and volume	The inside-hull test folds the vertical axis; the shell has no vertical offset and no cross terms of inertia	Each half tested separately; shell centroid and inertia from the real section
Added mass	Strip theory: the diagonal plus sway–yaw and heave–pitch couplings	Asymmetric sections also couple sway with roll and roll with yaw; BEM by default, which already returns the full 6×6
Cross-flow drag	One coefficient for flow from above and below, acting on the axis	Separate coefficients by direction, acting at each section's own centre
Hull lift	No camber; calibrated on the axisymmetric SUBOFF hull	A camber term (lift and moment at zero incidence), calibrated with CFD, since no published reference data covers it
Near the surface	Submerged fraction and free-surface model symmetric about the axis	Buoyancy split by half; free-surface model kept as an equal-area estimate
Search scoring	Drag at zero incidence; stability margins about a level, straight run	Trimmed angle of attack and fin angle solved at speed first; drag and margins scored there, with a cap on the trim angle

Already in place: the six-degree-of-freedom dynamics take a full mass matrix, component inertia is a full 3×3, and fins and thrusters can sit anywhere on the vehicle.

How we approach them

Asymmetric hulls lean hardest on the weakest parts of any low-order hull model: flow separation, hull lift and incidence. So the search does not score them until CFD has calibrated those terms, or it would find hulls that exploit the model rather than better hulls.

01 **Section model.** Upper and lower halves with separate crown and keel profiles; inside-hull test, shell moments and BEM meshing. Testable without new physics.

02 **Skin.** Upper and lower envelopes and Myring fits, a flat-keel option, and the new search variables.

03 **Hydrodynamics.** BEM added mass by default, directional cross-flow drag at section centres, split buoyancy near the surface, then the camber term in hull lift.

04 **CFD calibration.** Drag with separation, lift and pitching moment at zero incidence, and drag at trim, on a few representative shapes; the camber term and a separation penalty are fitted from them.

05 **Trimmed scoring.** Trim solved at speed, drag and margins scored there, a trim-angle rule added; then the drag–mass search runs with the asymmetric variables.

STARTING A STUDY

What we ask at the outset.

- **What drives the hull shape?** A flat bottom for downward-looking sensors, packaging, or behaviour near the surface. The answer sets which section shapes the search should offer.
- **What CFD can the study draw on?** Your tool and budget, or ours, and how many shapes it can afford.
- **Which component figures are real?** Masses and housings for navigation, sensors and payload. Assumed figures move the mass objective, so real ones make the result yours.

Shape search results are concept-stage and provided for planning and information. Where a result informs a design or safety-critical decision, it is reviewed by a partner professional engineer.

Have a hull to search?

Send us the components, the depth rating and the rules the layout must meet.

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