AUV Design: Shape, Drag and Practical Issues


HEADNOTE
Combining Practical and Hydrodynamic Considerations To Build a Better Autonomous Underwater Vehicle

Twenty years ago, autonomous underwater vehicles (AUVs) were an infant technology, and there was an absence of evolution to guide designers in deciding the fundamental shape and size of their craft. Since this period, researchers have tried a wide variety of AUV shapes and sizes, including torpedo shapes, like the National Oceanography Centre's (NOC) Autosub and Hydroid's (Pocasset, Massachusetts) REMUS; laminar flow bodies, like the early Kongsberg Maritime (Kongsberg, Norway) HUGIN vehicles; streamlined rectangular styles, like Atlas Elektronik GmbH's (Bremen, Germany) Sea Otter; and multihull vehicles, like the Woods Hole Oceanographic Institution's (WHOI) Autonomous Benthic Explorer (ABE). Each came with a vision of fulfilling a certain set of requirements and an oceanographic niche.

Most early AUVs were designed with a cruising speed of around two meters per second as a compromise between long endurance (requiring a slow speed) and making reasonable progress. It is probably true to say that most have fallen short of achieving the combination of design speed and range.

This has occurred for a variety of reasons. For instance, increased drag associated with antennae, lifting lugs and sensor protrusions, among other things, may have been glossed over, and the build is often heavier than anticipated - which is invariably overcome by carrying less energy (batteries). In addition, the propulsion efficiency may be less than hoped for due to poorly designed or matched propellers, and the expected battery energy density can be less than expected due to cold temperatures, high current drain or incomplete manufacturer's data. It is easy to overlook the energy overheads for premission checks, transit times and so on in the initial design estimates.

Many of these past errors (often due to optimism) can be easily corrected in a new analysis, but the effect of the shape and vehicle appendages on the hydrodynamic drag is harder to assess and has a significant impact on the performance of an AUV. This article considers these effects. Reynolds number (Re) and coefficient of drag (Cd) will be based on volume^{1/3} and volume^{2/3} respectively, to allow direct comparisons to be made with like-for-like volumes.

Effect of Slenderness Ratio

AUVs have tended to be designed around length-to-diameter (L/D) ratios of five to eight, mimicking in some respects naval torpedoes and aircraft drop tanks to provide the maximum volume for minimum drag. But AUVs have the additional design constraint of
having to be handleable at sea. A slender vehicle will need longer reach davits or booms to reduce the risk of collision with the mother ship during launch and recovery and will have a larger footprint on the ship's deck.

However, the Cd values for the National Advisory Committee for Aeronautics' (NACA) aerofoil solid of revolution versus L/D ratios of two to 10 show a surprisingly constant Cd down to a L/D value as low as three (excludes control surfaces).

Similar results are seen in early wind tunnel work performed on airship models. Thus, short, fat AUVs do not have a significantly higher Cd than slender ones and are inherently easier to handle and store on board a ship - although short vehicles may have stability issues that need to be considered. A more important drag consideration is the variation in drag between the idealized shape and the practical vehicle.

**Practical Versus Idealized Drag**

The less than expected range of the Natural Environment Research Council's (NERC) Autosub program during its proving trials led to a long investigation into its drag. The Cd of the body with control fins but no other appendages had been measured in a tow tank using a 0.743 scale model, giving a Cd of 0.029.1 In a post-build assessment, the panel misfit drag and drag of peripheral items not included in the model tests were estimated using published practical work and showed an increase in Cd of 24 percent above the scale model tests. The range still fell short of what would have been expected, but the only vehicle data used to determine drag was based on propulsive power consumption, which failed to separate the propeller efficiency from drag. A more direct approach to determine the actual Cd was achieved by logging the vehicle deceleration while pseudo-feathering the propeller drive (i.e., the propeller speed was reduced such that it neither induced thrust nor drag while the vehicle slowed). Only the initial part of the deceleration data is used since the vehicle deviates from straight and level flight at low speeds due to the positive buoyancy imposing a significant heave motion. However, the test is easy to add to the end of most missions, easy to repeat and provides a more direct measurement of drag.

These tests produced an estimated Cd of 0.045, which is considered reasonably accurate and correlates well with the achieved vehicle range. The estimated Cd value is 57 percent higher than that measured using the scale model in the towing tank, leading one to conclude that the drag of ancillary items needs to be properly estimated at the design stage if the range is an important part of the design specification. This is especially true when considering laminar flow bodies.

**Laminar Flow Body**

The laminar flow body achieves low drag by maintaining laminar flow over most of its length by virtue of its bulbous shape. The hull shape was used for the Unmanned Free-Swimming Submersible AUV and was considered during the early feasibility studies for Autosub, which culminated in extensive testing both in a wind tunnel and at sea.2,3 Since
then, the concept has been reconsidered as part of the U.K. Ministry of Defence's Battlespace Access Unmanned Underwater Vehicle (BAUUV) program, this time using the Fluent (Lebanon, New Hampshire) computational fluid dynamics (CFD) package to model the effects of surface faults on the shape's drag.

Early work estimated a minimum Cd of 0.007, and subsequent wind tunnel tests demonstrated a Cd value of 0.006 (Re=2.5 x 10^6) for a body with rudders and stern planes but no propeller. It was recognized that the standard of finish and fit of the outer body had to be extremely good for the concept to work, since any small perturbation on the forward section of the hull would trip the laminar flow and the advantage of the shape would be lost. NOC tested an instrumented scale model (with rudders and stern planes, no propeller) with a detachable tail joined in the aft turbulent region to keep the forward section smooth. The post-processed results gave a minimum Cd of between 0.013 and 0.015 (Re=2.3 x 10^6), roughly double the results found from wind tunnel testing.

Although the seagoing results fell short of expectations, illustrating the difference between real and idealized drag values, the Cd value was still lower than might be expected from a simple torpedo shape. The laminar flow shape also offers a good volume/length ratio, potentially easing some of the handling and storage issues compared with a long, slender body.

The more recent CFD-based studies examining the effects of hull imperfections show similar sensitivity. The imperfections were modeled by introducing both forward and rear-facing annular steps. Laminar flow hulls provide modeling difficulties when using CFD due to the transitional fluid flow, although codes are becoming increasingly accurate at predicting attached transition and now provide a flexible and reasonably accurate method of modeling discontinuities. The analysis of the hull was based on a 2D axi-symmetric case at an idealized 0° angle of attack, with a particularly fine mesh around the step (at least 10 cells within the near-wall viscosity-affected region). Mesh sensitivity studies showed little variance in Cd and separation position; hence, the mesh was considered adequate for the study. The CFD "smooth body" Cd is in reasonable agreement with the early theoretical work once corrected for the different Re values, further proving the CFD results.

The CFD work demonstrates how imperfections in the body form increase the smooth Cd value between 140 to 270 percent, depending on the position and direction of the step. The CFD results are in reasonable agreement with the sea trials, where a panel joint at the rear of the seagoing model appears to increase the Cd by 116 percent. These drag increases are the result of only minor imperfections in the ideal shape; the integration of communication and handling devices would require further (and necessary) investigation.

Conclusions

The accumulation of test data and practice helps assess the practicalities of new designs, and the tabulated summary gives an indication of how the actual Cd values compare with values taken in good faith at the design stage.
The ancillary systems added to the outside of an AUV and imperfections in manufacturing contribute significantly to the drag, although proportionately less to a torpedo form than to a laminar flow body. Items such as global positioning system aerials are now smaller than those produced 10 years ago, and fairing them into a slender mast has become easier. The degradation due to panel mismatch is difficult to quantify but is significant, and the quality of fit is closely related to the price paid for tooling and quality of manufacturing. Short hull designs have only modest increases in Cd and may prove to be more practical, easing problems of internal packaging, transport, launch and recovery and deck space requirements.

Laminar flow hulls may provide improvements as long as care is taken that the ancillary protrusions are distant from the laminar regime and do not dominate the overall drag so as to make the efforts worthless. With a more thorough approach at the design stage to fair in smaller communications aerials, this is becoming more practical.

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REFERENCE

References


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