Technical Meeting — 6 April 2022

Mathieu Courdier, PhD Candidate and Laurie Prandolini Scholarship holder, Australian Maritime College, gave a presentation on *Seakeeping of a Surfaced Underwater Vehicle* as a webinar hosted by RINA using the Zoom software platform with IMarEST Committee Member, Greg Hellessey, as MC on 6 April. This presentation attracted 23 participating on the evening.

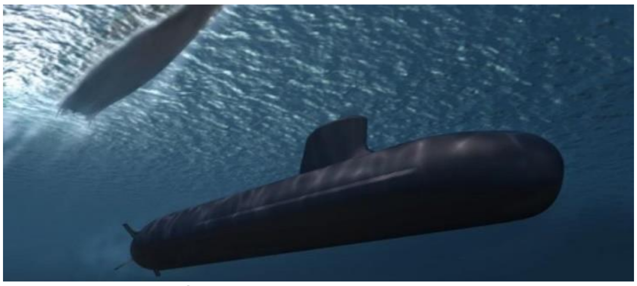
Introduction

Mathieu began his presentation by presenting different types of underwater vehicles. They include Naval Group's 18 m military underwater vehicle, Triton Submarines' leisure, commercial, professional and ultra-deep submersibles, autonomous underwater vehicles (AUVs) for research and, of course, Naval Group's Barracuda-class, the USA's Virginia-class, and the UK's Astute-class submarines.

Naval Group's 18 m military underwater vehicle
(Photo courtesy Naval Group)

(Photo courtesy Triton Submarines)

NATO CMRE research submersibles
(Photo courtesy NATO CMRE)



Naval Group's Barracuda-class submarine
(Photo courtesy Naval Group)

Why should we consider underwater vehicles? The planet has about 1400×10^6 km^3 of water volume, or about three times as much sea volume as land. We know far less about the sea than we do about the land mass. Also. more and more of humanity depends on the oceans for energy, for food, or for transportation. Thus the only way to effectively manage this is with machines that go underwater.

Underwater Vehicles

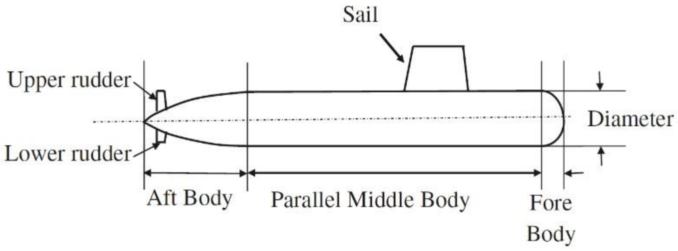
Underwater vehicles may be categorised in many ways. One way is to divide them into commercial, naval and special vehicles.

Commercial include research, industry and tourism underwater vehicles.

Naval includes nuclear-powered, conventionally-powered and midget submarines.

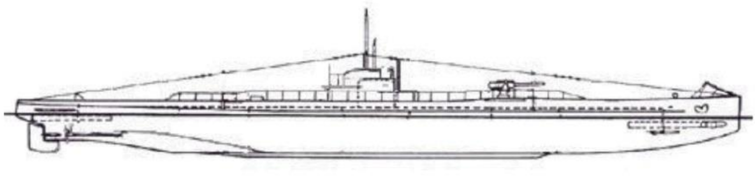
Special refers mainly to rescue craft which are typically carried by a surface ship and deployed for rescue operations.

A typical modern underwater vehicle has a parallel middle body, a hemispherical nose or fore body, a conical aft body, appendages including a sail and rudder, and a propulsion device. It is a ‘torpedo-shaped’ body which can benefit from the results of this research.



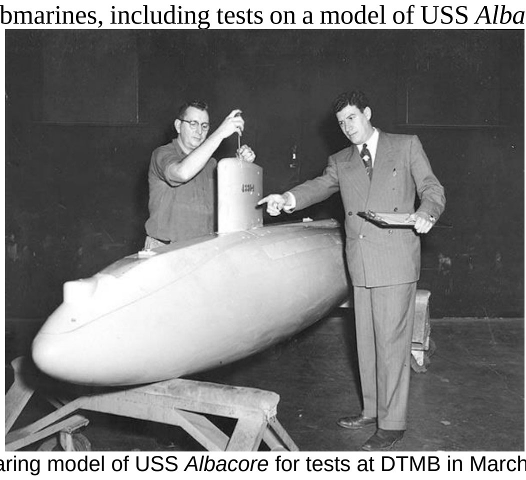
Typical modern underwater vehicle
(Drawing courtesy Martin Renilson)

The submersibles designed for World Wars I and II were based on surface ships, and their underbodies reflected that heritage rather than the modern shape. There was no magical transformation between the wars, and the shapes did not change much. The modern shape has developed from the substantial research which has been conducted since.



Typical WW I and WW II submarine
(Drawing courtesy Naval Historical Center)

In the early Cold War, the David Taylor Model Basin in the USA conducted a large amount of research on the best hydrodynamic shape for submarines, including tests on a model of USS *Albacore* in the towing tank in 1956.



Preparing model of USS *Albacore* for tests at DTMB in March 1956
(Official US Navy photograph courtesy Naval Historical Center)

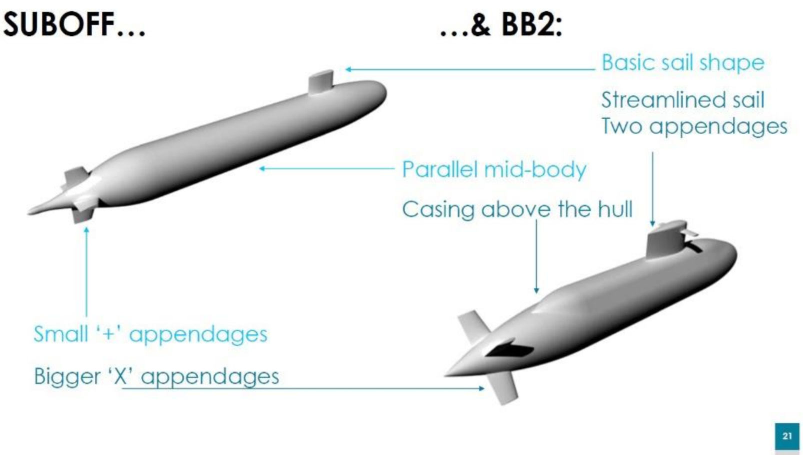
Here Mathieu showed a slide with twelve different types of underwater vehicles to show the extraordinary diversity now available, and a slide showing AMC's own autonomous underwater vehicle, *Nupiri Muka* [*meaning "Eye of the Sea" in palawa kani, the language of Tasmanian Aborigines; this AUV is capable of diving to 5000 m and aims to provide new insights into the role of Antarctica and the Southern Ocean in the global climate system* — Ed.]

AMC's autonomous underwater vehicle *Nupiri Muka*
(Photo courtesy AMC)

The largest submarines ever built were the six Soviets' Typhoon (Akula) class nuclear-powered ballistic missile (SSBN) submarines which were constructed at the Severodvinsk Shipyard, on the White Sea near Archangel. These vessels were 175 m long, had a surfaced displacement of 24 000 t and a submerged displacement of 48 000 t.

Typhoon-class submarine
(Photo from Naval Technology website)

There are two open-source submarine shapes on which much research has been, and is being, conducted. There are the Defense Advanced Research Projects Agency's Suboff model, developed at the David Taylor Research Center in the USA in 1989, and the Defence Science and Technology Organisation's BB2 model, developed by Peter Joubert in Australia from 2004.



Comparison of the Suboff and BB2 models
(Diagram courtesy Mathieu Courdier)

Why Surfaced Underwater Vehicles?

Simply, underwater vehicles (UVs) have to operate on the surface for some of the time—they all begin and end their operations there. Small UVs are launched on the surface, while large crewed UVs take on crew, fuel, water and stores on the surface before beginning their mission. Most need to be on the surface for communications. Conventionally-powered submarines must surface for air to run their diesel engines and to refresh the air for the people inside the hull.

A surfaced UV is subject to the waves on the water surface and, in addition, generates its own waves when running free, diving or surfacing. There is therefore much interest in the size and shape of the waves so generated.

Here Mathieu showed a video of the waves generated by a submarine running free on the surface.

Deployment of a research UV
(Photo courtesy NATO CMRE)

Deployment of *Nupiri Muka* in Antarctic waters
(Photo courtesy Mick Davidson)

Waves generated by a submarine travelling on the surface
(Photo courtesy Douglas Dammermuth)

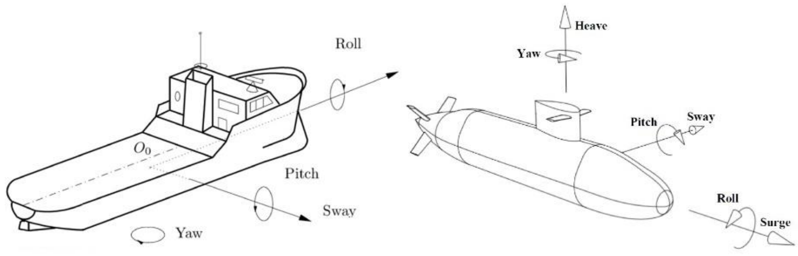
Submarines are at their most vulnerable when surfacing, and there have been a number of collisions with surface vessels while doing so. Here Mathieu showed the results of three such collisions of US Navy submarines, one with a badly-damaged sail, and one with a bent sail which cost $120 million to repair, and one of a Japanese Navy submarine with a badly-damaged fin on the sail.

Damaged sail on USS *Nautilus* (SSN 571)
(Photo from NavSource website)

Bent conning tower on USS *Hartford* (SSN 768)
(Photo from Wikimedia Commons website)

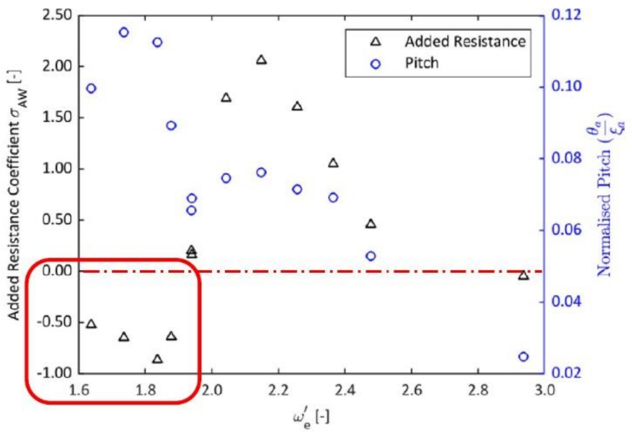
Damaged fin on sail of Japanese submarine *Souryu*
(Photo from BBC website)

Problem Definition
What needs to be understood —— is a submarine like a surface ship? A submarine, in general, travels in three dimensions, while a surface ship travels in two. So there is one additional level of complexity.



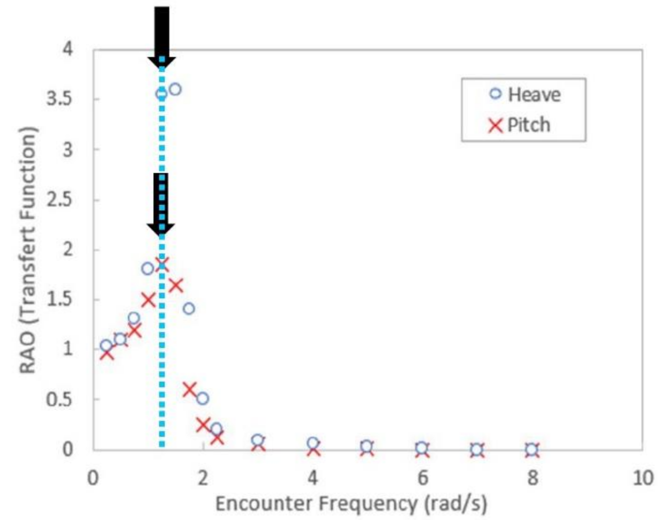
Comparison of degrees of freedom for a surface vessel and a submarine
(Diagram courtesy SNAME)

Also it has been shown at AMC since 2019 that underwater vehicles experience some hydrodynamic behaviours that are unheard of for surface ships. One difference is that the heave and pitch motion responses for a surfaced underwater vehicle are different to the ones of a surface ship. The known behaviour is a single peak in the amplitude of the heave and pitch motions for a given wave encounter frequency, whereas this becomes much more complex for a surfaced UV: the peaks of heave and pitch motion occur at different values of encounter frequency, and the peak heave motion occurs near a trough of pitch motion. As a result, submarines are more susceptible to adverse seakeeping behaviour than normal ships.



Added resistance coefficient vs encounter frequency
(Graph courtesy Mathieu Courdier)

Another difference is that the added resistance coefficient is negative for some low values of wave encounter frequency. This is a sign that the heave-pitch motion is coupled with some resistance parameters.



Non-dimensional pitch and heave motion response for a submarine
operating at Fr of 0.196 in 2.0 m wave height
(Graph courtesy Mathieu Courdier)

Seakeeping of a Surfaced Underwater Vehicle
Here Mathieu showed some slides of submarines operating on the surface in various conditions.

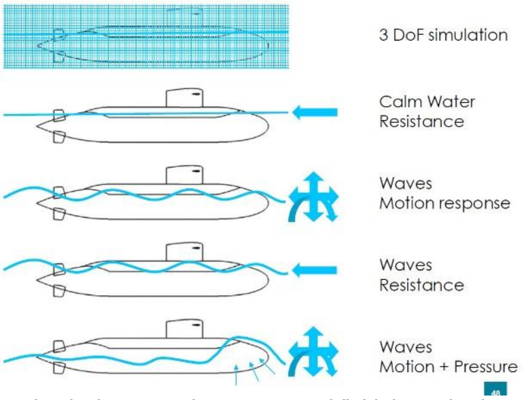
Surfaced submarine in heavy seas
(Photo courtesy Naval Group)

Royal Marine commandos deploying from an
Astute-class submarine in Lyngenfjord, Norway
(Photo courtesy Naval Group)

Research Impact
Who will benefit from this? The main question is *What is the seakeeping response of a surfaced underwater vessel in waves?* This can be subdivided into four separate questions.
What is the effect of *depth* on the seakeeping behaviour of a UV?
What is the effect of *wave parameters* on the seakeeping behaviour of a UV?
What is the effect of *hull shape* on the seakeeping behaviour of a UV?
What is the effect of *appendages* on the seakeeping behaviour of a UV?
The significance of the work is that it tackles the operational surface requirements for current and future UV projects.
It will directly benefit:

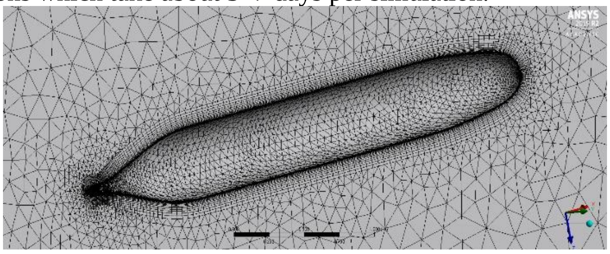
- Defence projects (i.e. navies around the world), and crewed submersibles.
- Research, science and exploration AUVs and ROVs.
- Industry needs for the energy and IT industries using robots and survey vehicles.
- Over time, from design to operation, by way of guidance for designers and operators.

The main novelty that this research brings to the field is a set of guidance for designers and operators, and some original fluid dynamics knowledge.

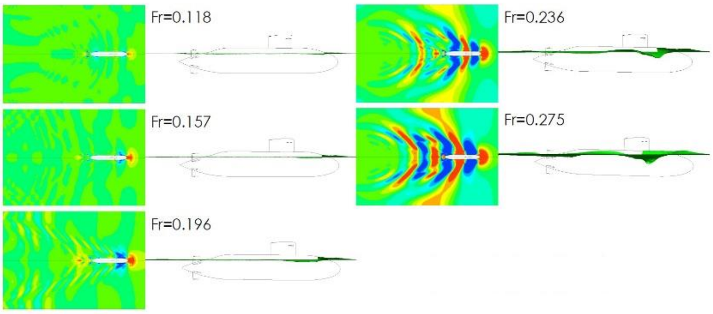


Guidance for designers and operators and fluid dynamics knowledge
(Diagram courtesy Mathieu Courdier)

Methodology
This is what I actually do! It involves both computational fluid dynamics (CFD) and experimental fluid dynamics (EFD)
EFD is the "real world" visualisation; it takes time, is expensive, and challenging.
CFD is the mathematical model of the physics; it also takes time, is also expensive, and is still challenging!
We use experiments to feed in to the mathematical model and check that the model is working as it should. We then run case scenarios to find better solutions, and then can run better experiments to investigate some points in more depth.
The CFD mesh of the 1.69 m Suboff model which I am using has 10 million points in the mesh, and the computer uses 120 cores for calculations which take about 5–7 days per simulation.

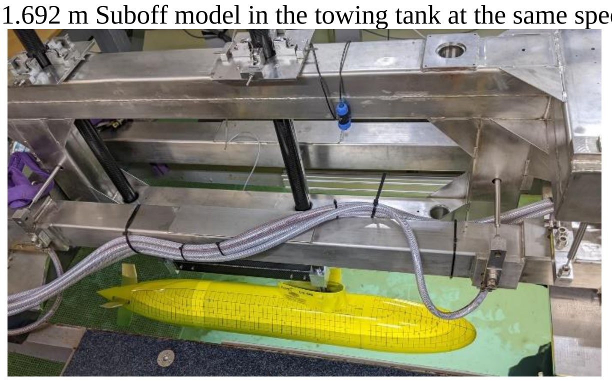


CFD mesh for Suboff model
(Drawing courtesy Mathieu Courdier)



CFD results for 1.692 m Suboff model operating at speeds of
0.48 m/s (Fr = 0.118) to 1.12 m/s (Fr = 0.275)
(Diagrams courtesy Mathieu Courdier)

The EFD involves testing a 1.692 m Suboff model in the towing tank at the same speeds as run in the CFD.

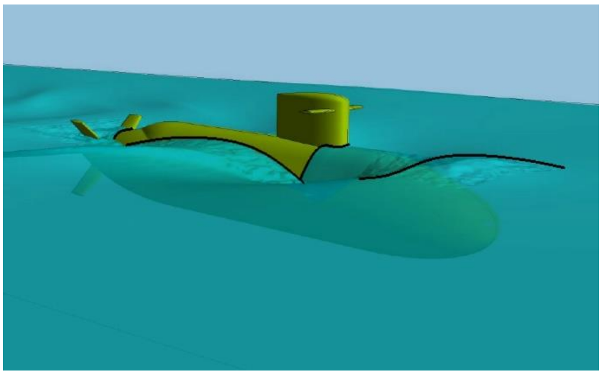


The submarine model in the towing tank
(Photo courtesy Mathieu Courdier)

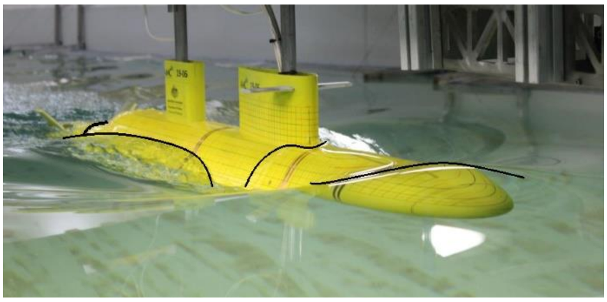
The submarine model being tested in the towing tank
(Photo courtesy AMC)

Verification and Validation

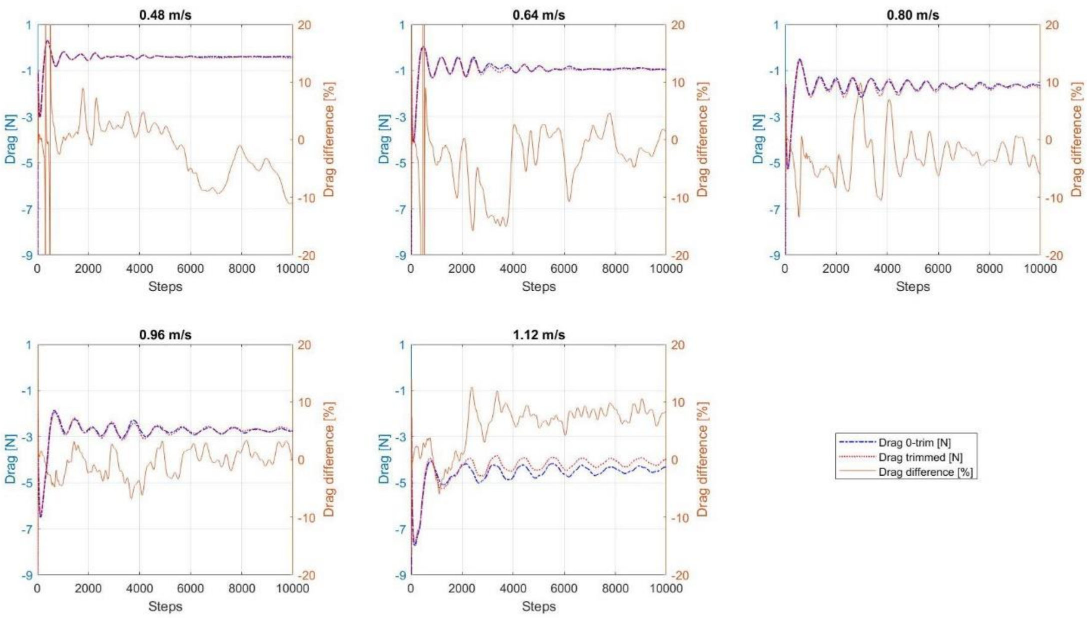
Results so far have shown good agreement between the CFD predictions of waves generated by the Suboff model and the waves generated by the model in the towing tank and the run-up of water onto the hull and the base of the sail.



CFD results for model wave generation at 1.12 m/s (Fr = 0.275)
(Image courtesy Mathieu Courdier)



EFD results for model wave generation at 1.12 m/s (Fr = 0.275)
(Photo courtesy Mathieu Courdier)



CFD calm water resistance results for model at various speeds vs time steps
(Graphs courtesy Mathieu Courdier)

The experimental results so far have provided the verification and validation of the CFD results, and verified the calm-water resistance predictions. The design and manufacture of the new test rig now allows us to test some conditions that we were not able to do with the old one. This is instrumental in developing the next CFD simulations. I now have to test the effects of wave parameters, hull shape variations, and the influence of appendages.

Conclusion

Underwater vehicles are widely used in the industrial and scientific world, as they allow for easy, safe and cheap access to operations. Submarines also are important in navies as they provide unrivalled operational advantages. Despite being used at depths, UVs are required to travel on the sea surface for some period of time and for critical operations, where they are subject to waves. However, most of the hydrodynamic knowledge applicable to conventional surface ships is not relevant to UVs due to their particular hullforms. Also, hydrodynamics is of paramount importance, as it defines the ability of a UV to carry out its mission: hence seakeeping, resistance and manoeuvrability form the subjects of this research.

The research undertaken here uses computational fluid dynamics which allows modelling of the fluid flow around an UV hull. The variation of such parameters as the speed, the wave height and the hull shape helps to understand the flow dynamics. The CFD model has been validated using experimental fluid dynamics, and the calm water resistance measured. The project now leads on to testing the effects of wave parameters, hull shapes and appendages.

Acknowledgements

Mathieu acknowledges

- IMarEST for the grant of the Laurie Prandolini Scholarship and the Stanley Grey research fellowship, and their continued support for the project;
- DST Group for their support with experimental techniques; and
- RINA for organising this presentation.

Questions

Question time raised some further interesting points.

On the diagram showing non-dimensional pitch and heave for the submarine, there are two peaks for the pitch response—and it is not known why!

The scale factor here between the CFD and EFD is 1:1, i.e. using a 1.692 m model. The full scale BB2 model was 70 m long, and clearly too large to fit into the AMC towing tank. However, the model is perfectly scalable, and has been tested around the world at many different scales.

The model will be tested in head seas first and, if time permits, then at other orientations to the waves. However, this is for one PhD degree, not several!

The model has so far been tested only on the surface at a typical surfaced displacement but can, of course, be tested at varying depths of submergence.

To dampen pitching motions, we need to understand that different speeds, wave heights and encounter frequencies result in different pitching motions. We can use gyroscopes, water ballast, etc., depending on the case.

Free water in free-flooding spaces is really hard to simulate. In the BB2 model there is no flooding water, so the free-flooding tanks are not considered.

The presentation was recorded, and is expected to be available soon on the RINA YouTube channel.

The certificate was subsequently posted to Mathieu, and the “thank you” bottle of wine delivered via an eGift card.