Appendix: Calculations for a full 70-day mission on one battery charge

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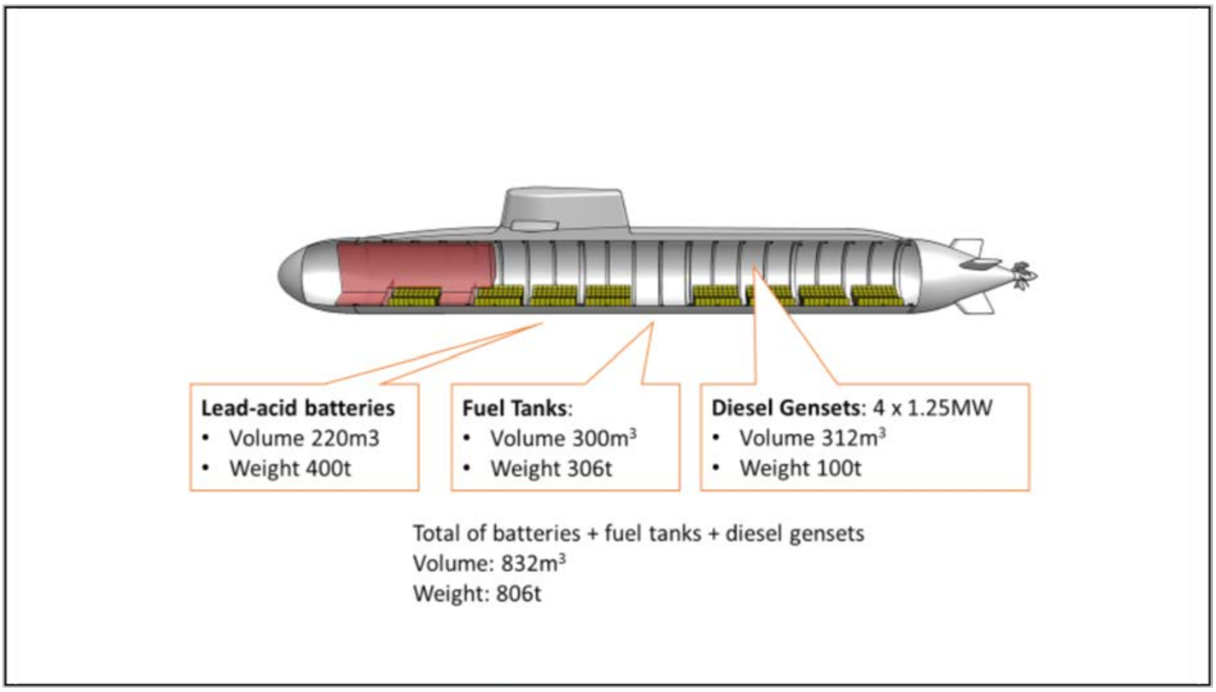
In ‘Future-proofing the Attack class (part 2): performance and capacity’, Derek Woolner and David Glynne Jones suggest that an advanced light metal–air battery could replace the original lead–acid battery, diesel fuel and engines together in one package by the mid-2040s, enabling a submarine to complete a full patrol on a single charge.

I ran the numbers to test whether that’s likely to be possible, for a generic 3,000-tonne conventional submarine performing a 70-day mission profile. My conclusion is that it is not.

The diagram below represents a generic 3,000-tonne conventional submarine with an 8-metre diameter. Note that the Attack class will be at least half as big again in tonnage. My calculations are rudimentary and ignore adjustments for loss of volume due to case hardening and separation of the batteries, and all safety and integration issues. Also be aware that due to the high energy density, the lithium batteries are volume limited and the submarine will need extra weight for stability, weight and trim balance. But let’s just assume that the swap is possible.

A generic 3000-tonne diesel electric submarine showing approximate volumes and weights for replacement of lead–acid batteries, fuel tanks and diesel gensets with lithium chemistry



A lead-acid battery is about 13% of the displacement but only 3% of the volume of a 3,000-tonne conventional submarine. So if the 400 tonnes of lead–acid of a 3,000-tonne submarine are replaced by a light-metal battery, the volume will be the same (3% or about 220m^3), but more weight must be added low in the submarine to keep its weight, stability and trim in balance.

The capacity of the lead–acid battery will be about 22,000 kWh and the lithium-ion battery replacing it would be about 44,000 kilowatt hours, assuming an ambitious doubling of capacity. The energy density of the lead-acid battery will be 22,000/220 = 100 kWh/m^3, with the lithium-ion battery being 44,000/220 = 200 kWh/m^3.

In the lead–acid submarine, assume the fuel tanks will be some 300 m^3 in volume, weighing about 306 tonnes when full, and the diesels will occupy about 312 m^3 weighing about 100 tonnes. The total of lead–acid battery, fuel and diesel engines will be about 832 m^3 and 806 tonnes.

If we designed a 'full lead–acid' submarine and replaced the fuel and diesel engines with lead–acid batteries, because lead–acid is weight limited we could get 806t/400t, or about twice the capacity of the original submarine.

And if we designed a 'full lithium-ion' submarine (replacing batteries, fuel and diesel engines), we would have 832 m^3 and 806 tonnes available for the lithium battery. We could expect a battery capacity of 832m^3/220m^3 or 3.8 times the lead–acid submarine.

Is this enough for a full patrol of 70 days?

We should assume an indiscretion ratio—call it an ambitious 15% for the sake of the calculation. That means the total diesel plant running time would be 70 days x 24 hours x 15% = 252 hours. With an assumed diesel plant of 4 x 1,250 kW = 5,000 kW, the total energy needed would be 252 hours x 5,000 kW or 1,260,000 kWh.

If we divide the total energy requirement by the battery capacity, the number of recharges of the original lead–acid submarine for 70 days would be the total energy generated divided by the battery capacity—that is, 1,260,000 kWh/22,000 kWh or 57 full recharges.

For a lithium-ion battery submarine, if we divide the total energy requirement by the lithium battery capacity, the number of recharges required would be 1,260,000 kWh/44,000 kWh or 29 recharges.

Assuming the Woolner–Jones 'gigabattery' submarine fitted with a lithium-air battery (a new type of battery using oxidation and reduction of lithium) with no fuel and no diesel engines, just pure battery, the advanced batteries of the mid-2040s would need to have their energy density improved by nearly 30 times the most ambitious present-day lithium batteries or some 60 times the capacity of lead–acid batteries. At the moment, this is science fiction drawn from laboratory testing.

Note: Lithium-air batteries need an atom of oxygen for one atom of lithium—or, for a 'super' battery, two atoms of oxygen for each atom of lithium—so the air needed will be equivalent to running diesel engines. For a full patrol, we would need 4,000 tonnes of air (or maybe 800 tonnes of liquid oxygen) in place of the original lead–acid batteries, fuel and diesels.