



UNIVERSITÀ  
DEGLI STUDI DI TRIESTE

*Vittorio BUCCI*

**Progetto di impianti di propulsione navale**

## **6.2 APPLICAZIONI NELLA PROPULSIONE**

---

Anno Accademico 2017/2018

# Impianti di propulsione navale

## Il punto di vista di un costruttore di motori diesel (WÄRTSILÄ) sull'applicazione della propulsione CODLAG nelle navi da crociera

**CODLAG stands for Combined Diesel-electric and Gas Turbine machinery. This means that there is at least one diesel engine and one gas turbine driving generators to create electric power for both the propulsion and the hotel side.**

**Although the CODLAG cruise ships currently on order are based on different design principles, they have the same basic machinery concept.**

**Princess Cruises was the first company to announce their decision to equip four of their cruise ships with CODLAG machinery.**

**At the time of writing they have two Post-Panamax 'Grand' class vessels under construction at Mitsubishi in Japan and two smaller Panamax vessels, 'Baby Grand', at Chantiers de l'Atlantique in France.**

**The new Grand class vessels each feature two 9-cylinder Wärtsilä L46 and two 8-cylinder L46 medium-speed diesel engines as well as one LM2500+ gas turbine. The 'Baby Grand' vessels have two 16-cylinder Wärtsilä V46 engines and one LM2500+ gas turbine each.**

## Impianti di propulsione navale

**In all the Princess Cruises CODLAG vessels, the gas turbine is placed in the funnel at the sun deck level. The idea behind this unconventional location is to make the very large air intake and exhaust ducts shorter in order to save space.**

**Holland America Line has also selected CODLAG machinery for their new Vista class cruise ships from Fincantieri. However, they chose a more conventional arrangement with both the diesel engines and the gas turbine located below the bulkhead deck in the hull. These vessels have three 16-cylinder and two 12-cylinder Sulzer ZA40S engines and one de-rated LM2500 gas turbine.**

**Three of the diesel engines are located in the aft engine room. This is separated by a watertight main fire bulkhead from the forward engine room, which houses the two remaining diesel engines and the gas turbine.**

**The Vista ship has a much larger installed diesel engine power than that of the Princess vessels.**

**This enables the Vista ship to operate in all modes on diesel engines alone.**

**The turbine does not need to be used unless one or more engines are out of service. If desired, the turbine can of course be taken on line parallel with the diesel engines or as a stand-alone unit in port.**

# Impianti di propulsione navale

Owner	HAL	Princess Cruises	Princess Cruises	Cunard
Name	Vista class	Baby Grand class * Coral Princess * Island Princess	Grand class * Diamond Princess * Sapphire Princess	Queen Mary 2
Number of ships	5	2	2	1
Yard	Fincantieri	Chantiers de l'Atlantique	Mitsubishi HI	Chantiers de l'Atlantique
Gross Tonnage	84,000	88,000	113,000	150,000
Cabins	900	975	1300	1310
Machinery	2 x Sulzer 12ZA40S 3 x Sulzer 16ZA40S 1 x LM 2500	2 x Wärtsilä 16V46C 1 x LM2500+	2 x Wärtsilä 8L46C 2 x Wärtsilä 9L46C 1 x LM2500+	4 x Wärtsilä 16V46C 2 x LM2500+
Diesel kW (%)	51,840 kW, (78 %)	33,600 kW, (57 %)	35,700 kW, (59 %)	67,200 kW, (57 %)
GT kW (%)	14,500 kW, (22 %)	25,000 kW, (43 %)	25,000 kW, (41 %)	50,000 kW, (43 %)
Total power kW	65,340 kW	58,600 kW	60,700 kW	117,200 kW

# Impianti di propulsione navale

## **CODLAG for smokeless operation**

**One of the likely reasons why both Princess Cruises and Holland America Line selected the CODLAG concept was to be able to operate without any smoke formation in special areas such as Alaska. Some cruise ships have been given a fine for emitting visible smoke, which is regulated in Alaskan waters. It is especially important for these two companies to comply with the Alaskan regulations, since both have many cruise ships operating on Alaskan itineraries. Conventional diesel engines may produce some visible smoke when operating at low loads or during rapid load transients.**

**The CODLAG alternative was chosen to meet the requirement for smokeless operation. It was envisaged that the ship could operate exclusively on the gas turbine, or by operating the diesel engines at constant high load and letting the gas turbine handle the load variations.**

**With diesel engines of new generation now available, there is no need to install gas turbines in cruise ships for operation in local 'no smoking' zones.**

**Most recent diesel engines, such as Wartsila EnviroEngines, employ common-rail fuel injection for smokeless operation at all loads and even during transients.**

# Impianti di propulsione navale

## **CODLAG for high power output**

**The machinery selection for Cunard's ocean liner Queen Mary 2 was based on other reasons.**

**The world's largest passenger vessel has a very high power demand, due to its large size and high speed. This puts emphasis on some unique machinery characteristics. CODLAG machinery offers a compromise between low weight and space demand for high power and good economy from the diesel-electric plant.**

**Queen Mary 2 has four 16-cylinder Wärtsilä V46 EnviroEngines and two gas turbines. The total installed power is almost 120 MW. This engine arrangement has been selected based on the special operation profile, the expected fuel prices and the space demand of the machinery.**

# Impianti di propulsione navale

## Case study vessel

**A CODLAG arrangement has been configured for a typical Panamax cruise ship (Fig. 2). In this case the vessel will be used for benchmarking against cruise ships with other machinery concepts. The proposed CODLAG machinery has four 8-cylinder Wärtsilä L46 engines, each generating 8400 kW, giving a total diesel power of 33,600 kW and one 25,000 kW gas turbine. The total installed power is therefore close to 59 MW. The output power ratio between the diesel engines and the turbine is 57 % to 43 %.**

**This concept is quite similar to that of the Princess Cruises ships. The installed power is the same as in their Panamax vessel, but there are four in-line diesel engines instead of two large V-engines.**

**This is the same principle as in the Grand class vessels. It provides good flexibility and enables the engines to run closer to their optimum load, which in turn improves the fuel economy. In this way it is also easier to perform maintenance on one engine without affecting the available power too much.**

**The proposed CODLAG machinery will be compared against two reference vessels. The first is a diesel-electric ship with six 9-cylinder Wärtsilä L46 engines, similar to the new successful Carnival Spirit class.**

**The other reference vessel has a COGES (Combined Gas Turbine and Steam Turbine Electric System) machinery with two 25 MW gas turbines and one 7 MW steam turbine, similar to the power plant found in the Millennium and Vantage class ships.**

# Impianti di propulsione navale

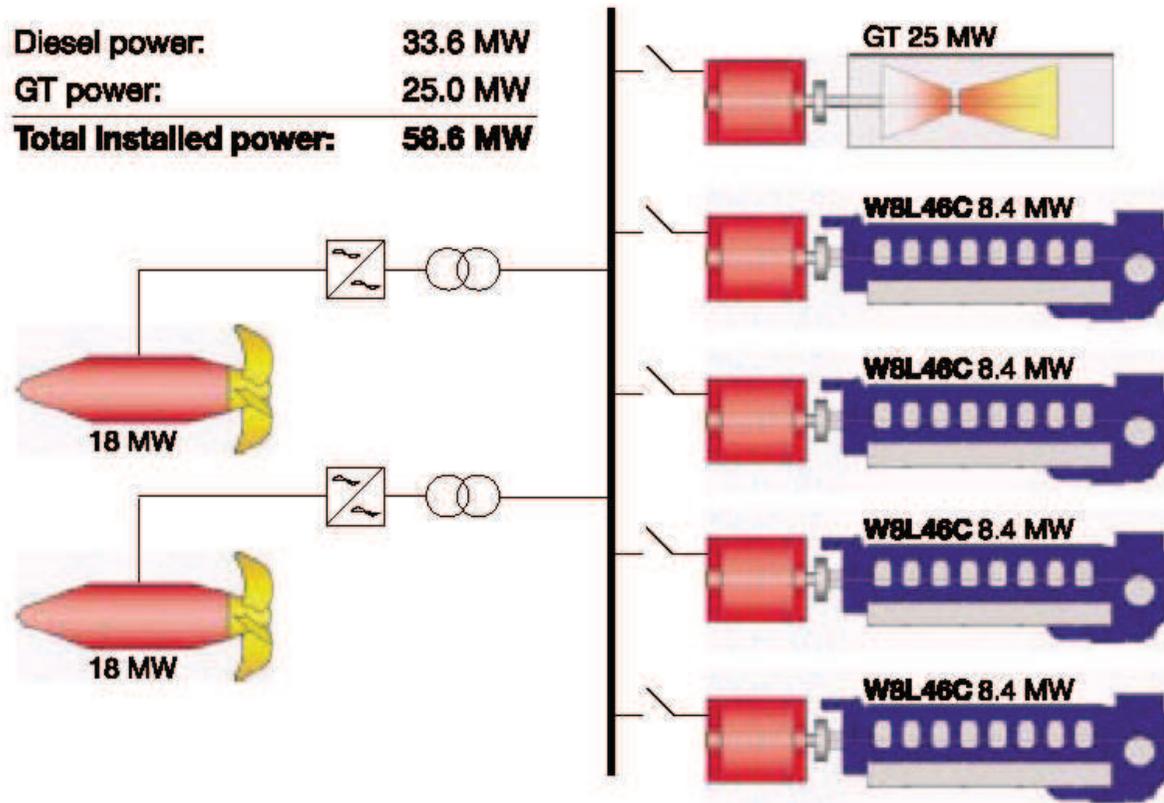


Fig. 2 A CODLAG arrangement consisting of four medium-speed diesel engines and one gas turbine.

# Impianti di propulsione navale

## Operation of the CODLAG ship

**There are various ways to operate a CODLAG ship. The most economical way is to use the diesel engines as much as possible and only use the gas turbine as a booster unit when the power demand exceeds the available diesel output.**

**However, one of the reasons for selecting CODLAG machinery was to avoid smoke formation at part load and during load-ups. This means that the gas turbines might be operated also in port, when manoeuvring and when running at moderate speeds. This has a clear negative impact on the fuel economy of the vessel.**

**Two extreme operation modes are used in this comparison. In the first mode the diesel engines are used as the primary power source and the gas turbine is started only when the power demand exceeds the available diesel power. The other mode is the opposite: the gas turbine is used to cover the base load and the diesel engines act as boosters. In real life a CODLAG ship will operate somewhere between these two extreme modes and the actual operation mode will depend a lot on the itinerary in question.**

## Fuel consumption

**The specific fuel oil consumption (SFOC) of a typical large gas turbine is much higher than that of a medium-speed diesel engine.**

## Impianti di propulsione navale

**Consumption is particularly high at part load and can reach a level well above 400 g/kWh. At maximum load the consumption is still above 230 g/kWh. Compare this with the consumption of a large medium-speed diesel engine, which is below 175 g/kWh at high load. Nor is the consumption of the diesel engine as load-dependent as that of the gas turbine; it increases only by about 30 g/kWh when the load is dropped to 20 %.**

**This large difference in SFOC between the gas turbine and the diesel engine gives rise to some of the typical characteristics of a CODLAG machinery. The consumption is very low when the ship is operating on diesel engines alone, but increases rapidly when the gas turbine is started. The fuel consumption of the prime movers in the alternative ship concepts is shown in Figure 3.**

**Lower fuel consumption is not the only factor favouring the use of diesel engines over gas turbines. Gas turbines also demand high-quality fuel such as marine gas oil (MGO), which is significantly more expensive than heavy fuel oil (HFO), normally used in diesel engines. Indeed, the price of MGO can be twice as high as HFO. The fuel cost of the alternative concepts in different operation modes is indicated in Figure 4.**

**The cost of the COGES concept is the highest while the pure diesel-electric ship running on HFO has the lowest cost in all operation modes. The fuel cost of the CODLAG ship is similar to that of the diesel-electric ship when only the diesel engines, which burn HFO, are operated.**

# Impianti di propulsione navale

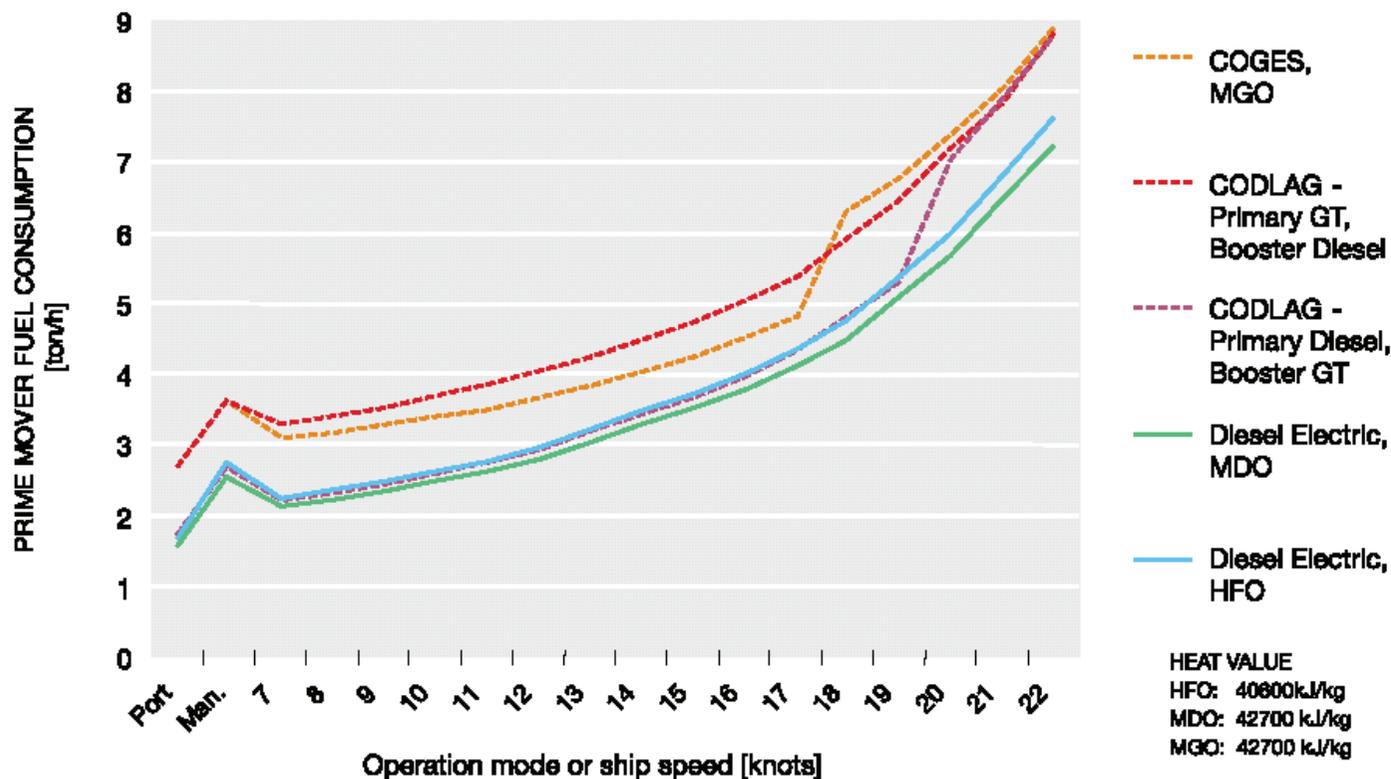


Fig. 3 Prime mover fuel consumption in a Panamax-max vessel with alternative machinery concepts.

## Impianti di propulsione navale

**The fuel cost increases rapidly when the gas turbine is started. Also the diesel-electric ship operating on marine diesel oil (MDO) has a lower fuel cost than that of the COGES ship. The comparison takes account of differences in both power and heat demand. The fuel of the oil-fired boiler is also included to give the complete picture. The total annual fuel cost of the alternatives is calculated for the cruise ship operating profile shown in Figure 4.**

**The fuel and lubricating oil cost of the COGES ship is almost 125 % higher than for the diesel-electric version. The corresponding figure for the CODLAG is 14 % to 117 % depending on which operation mode is applied. The lower consumption cost is achieved when the diesel engines are the primary power source and the gas turbine is used only as a booster.**

### Emissions

**The emissions of the alternative cruise ship concepts are illustrated in Figure 5. The diesel-electric ship equipped with selective catalytic reduction (SCR) units and operated on marine diesel oil is clearly the most environmentally friendly ship with respect to all emissions.**

**The higher fuel consumption of the gas turbine ships results in correspondingly higher CO<sub>2</sub> emissions. The SO<sub>x</sub> emissions depend on the fuel consumption and on the sulphur content in the fuel.**

# Impianti di propulsione navale

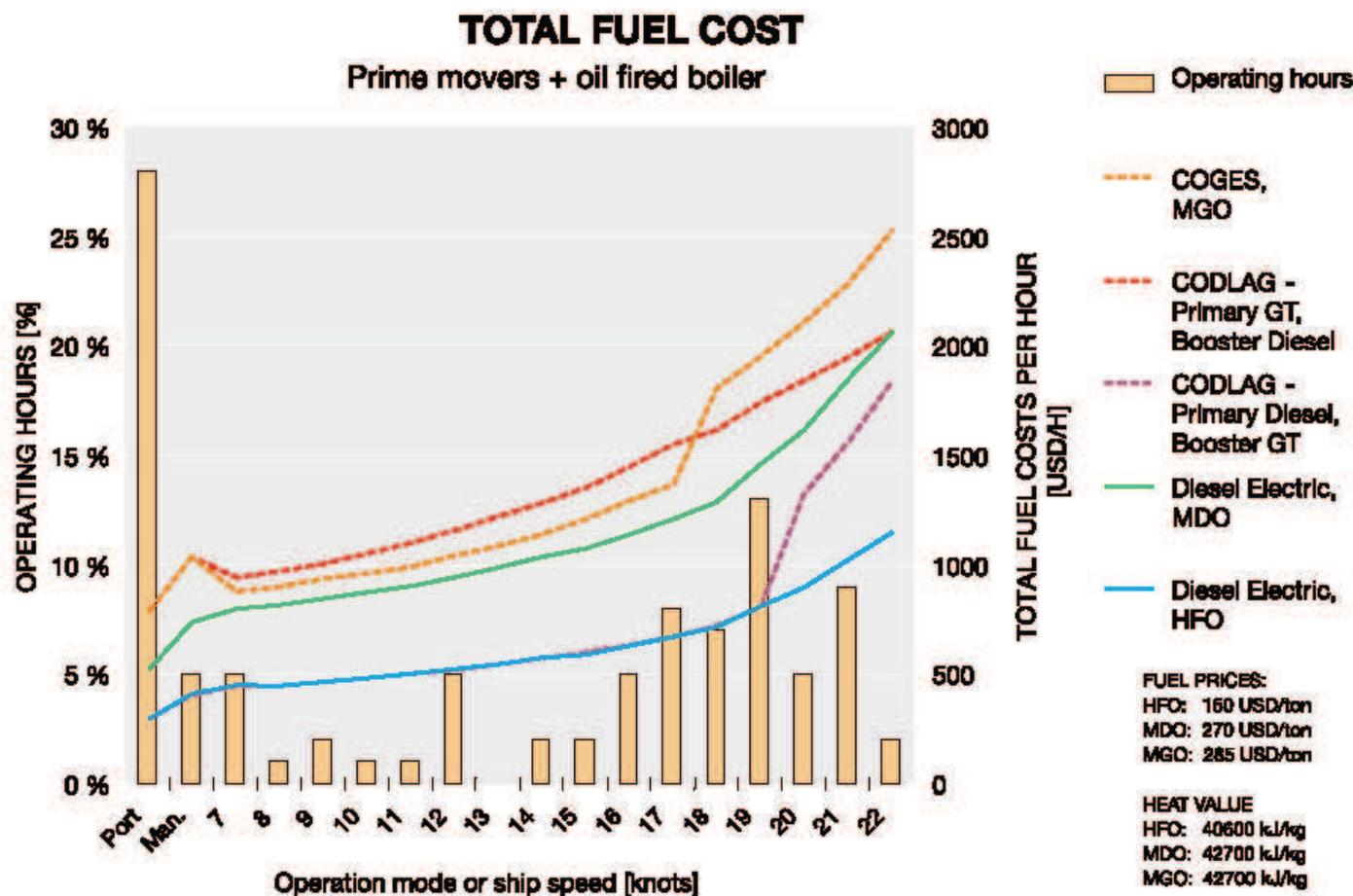


Fig. 4 Fuel cost at different speeds for a Panamax-max vessel.

# Impianti di propulsione navale

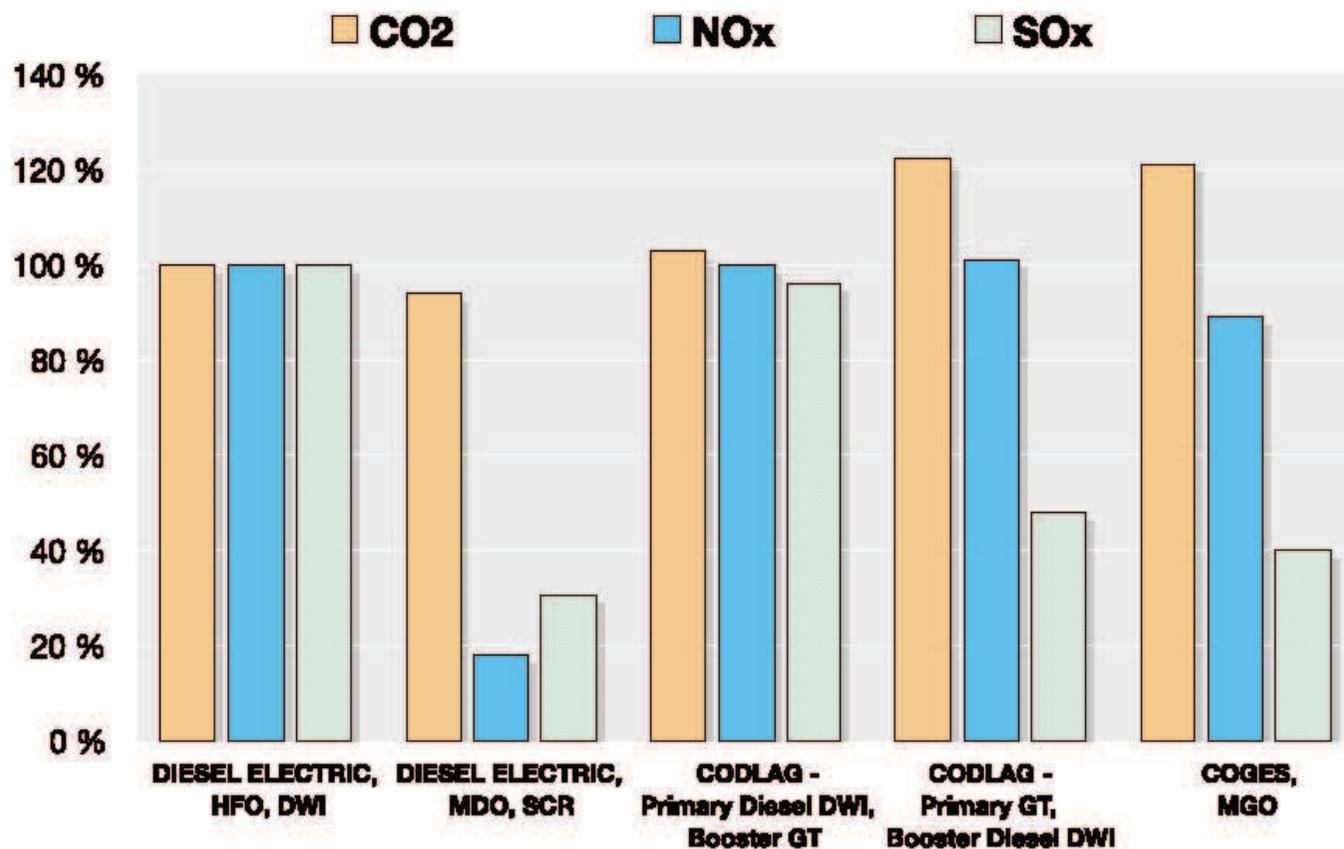


Fig. 5 Total exhaust emissions relative to diesel-electric machinery. Both the prime movers and the oil-fired boilers are included in the values. The diesel engines running on HFO are equipped with Direct Water Injection.

# Impianti di propulsione navale

**The NO<sub>x</sub> level of a gas turbine is lower than that of a standard diesel engine. However, a diesel engine with direct water injection (DWI) can reach the same NO<sub>x</sub> levels as the gas turbine. The DWI system can also use cleaned and filtered grey water, so no extra freshwater production is needed.**

## Space and weight

**A gas turbine machinery is lighter than a diesel-electric machinery with the same power output. However, the most critical design issue in a large Panamax cruise ship is stability, not the weight in itself. Since the beam of the vessel is limited by the Panama canal, the stability cannot be improved by increasing the beam.**

**Hence, permanent ballast has to be added to the ship in order to lower the vertical centre of gravity. A 57 MW COGES power plant is about 1000 tons lighter than a corresponding diesel-electric plant. Some of the recently built COGES ships have 1300 tons of ballast, which more than cancels out any weight advantage. The weight of the CODLAG machinery is somewhat lower than that of a diesel-electric machinery. Locating the gas turbines on the sun deck does not help to improve the stability, but it does offers other interesting benefits.**

**A gas turbine is also smaller than a diesel engine. The machinery space demand is therefore reduced in both alternatives with gas turbines. However, not all the saved space can be used for additional passenger cabins.**

## Impianti di propulsione navale

**When the number of cabins is increased, the public spaces, service spaces and technical spaces in the accommodation should also be increased to maintain the same volume per passenger ratio. Also the number of hotel crew members and their spaces should be increased correspondingly.**

**The difference in machinery space demand between a diesel-electric plant and a COGES plant is about 3000 m<sup>3</sup> in a Panamax vessel. The CODLAG lies somewhere in between. When the same ship standard is maintained, there will be room for about 10-15 extra average sized cabins in the COGES ship compared to the diesel-electric ship. All additional cabins will be inside cabins low down in the hull. The CODLAG ship with the gas turbine located in the funnel will save some more space than the version with all generating sets located below the bulkhead deck, due to the shorter air intake and exhaust ducts. However, this vessel loses some very valuable space on the sun deck level. This is of course a question of preferences, but the “value” of spaces in different locations should be noted at the ship concept design stage.**

### **Total economy**

**The required ticket rate (RTR) of the alternative cruise ship concepts is calculated to compare their economic performance. The RTR value gives the minimum price that the operator should charge per average passenger per day to break even. The RTR also includes sales costs like travel agent commissions, discounts and marketing.**

## Impianti di propulsione navale

**All aspects have been included in the comparison such as the number of cabins and cost items such as fuel, crew, lubricating oil, maintenance and investment costs. Figure 6 shows that the conventional diesel-electric ship operating on HFO is the most economical alternative. The CODLAG ship is only slightly more expensive. The COGES ship offers the least favourable economic result. The most environmentally friendly alternative, the diesel-electric ship operating on marine diesel oil and equipped with SCR units, is also better than the COGES ship from the economic point of view.**

# Impianti di propulsione navale

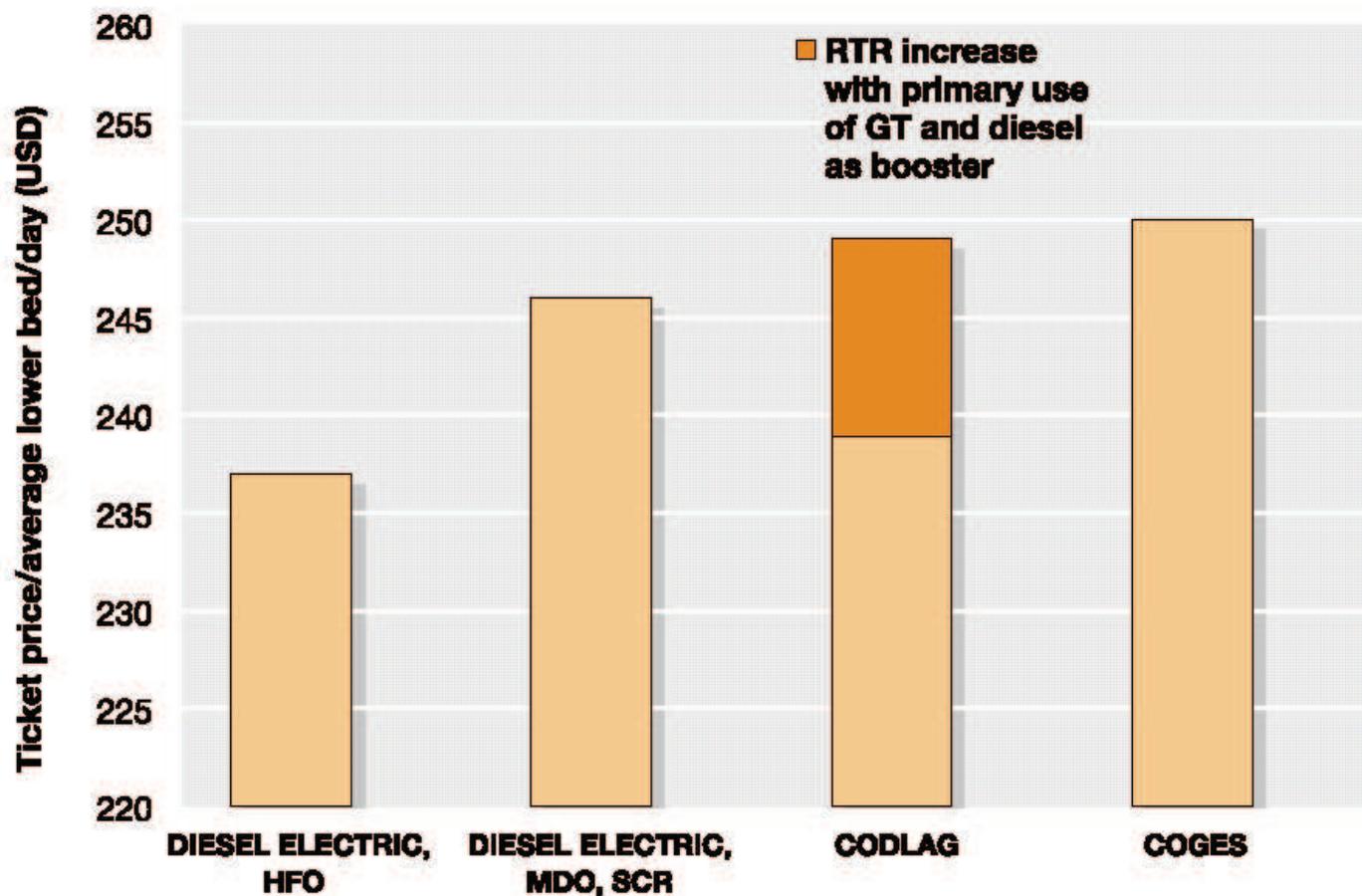


Fig. 6 Required ticket rate for the alternative Panamax-max ship concepts.

# Impianti di propulsione navale

## Summary

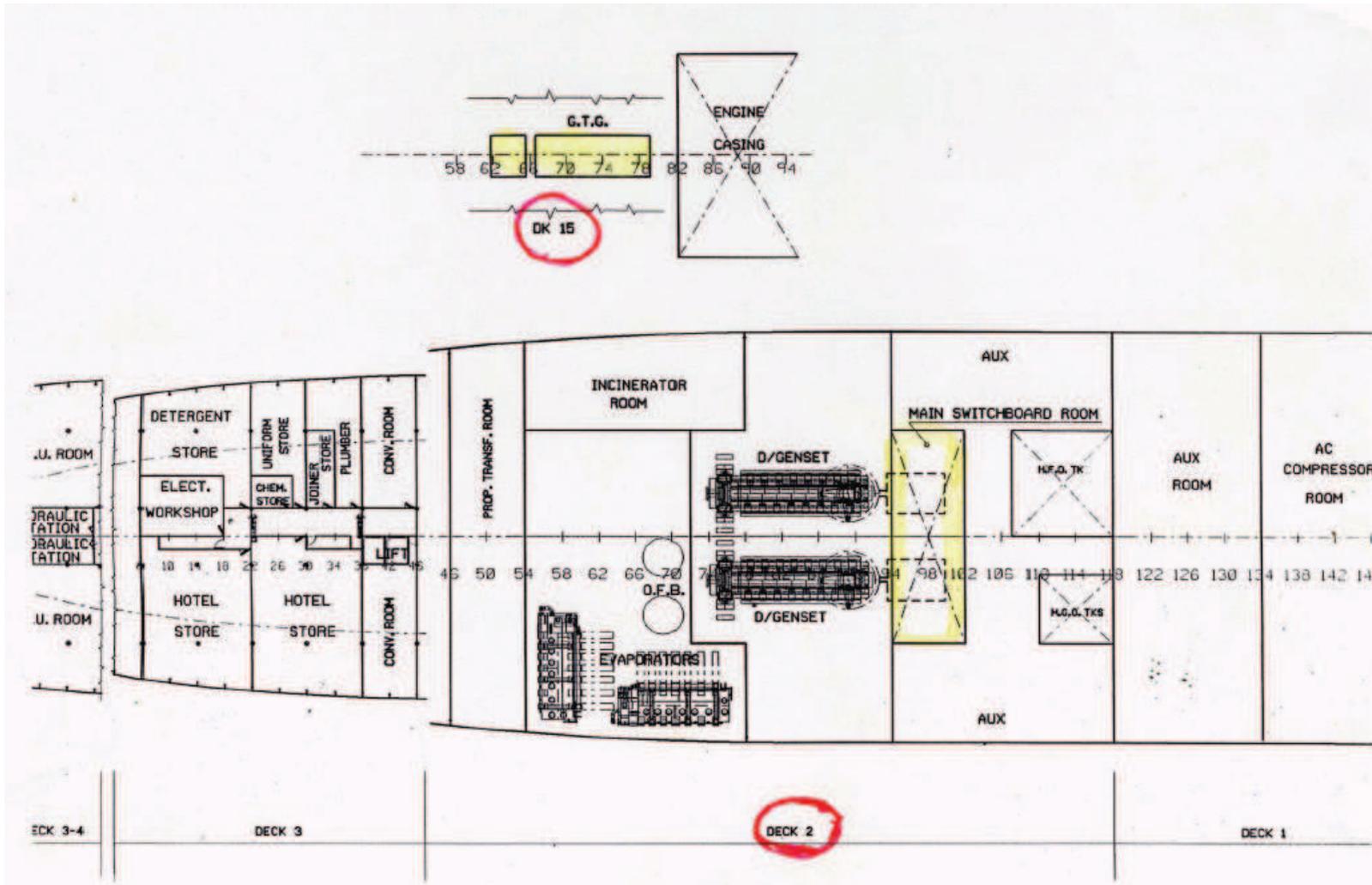
**The CODLAG ship performs better than a COGES ship, but it cannot reach the same economic performance as the pure diesel-electric ship. One of the initial reasons for selecting CODLAG was to avoid smoke formation in restricted areas.**

**This is no longer necessary now that advanced Common Rail technology in diesel engines is available. All visible smoke can now be avoided and there is no need to rely on gas turbines for smokeless operation.**

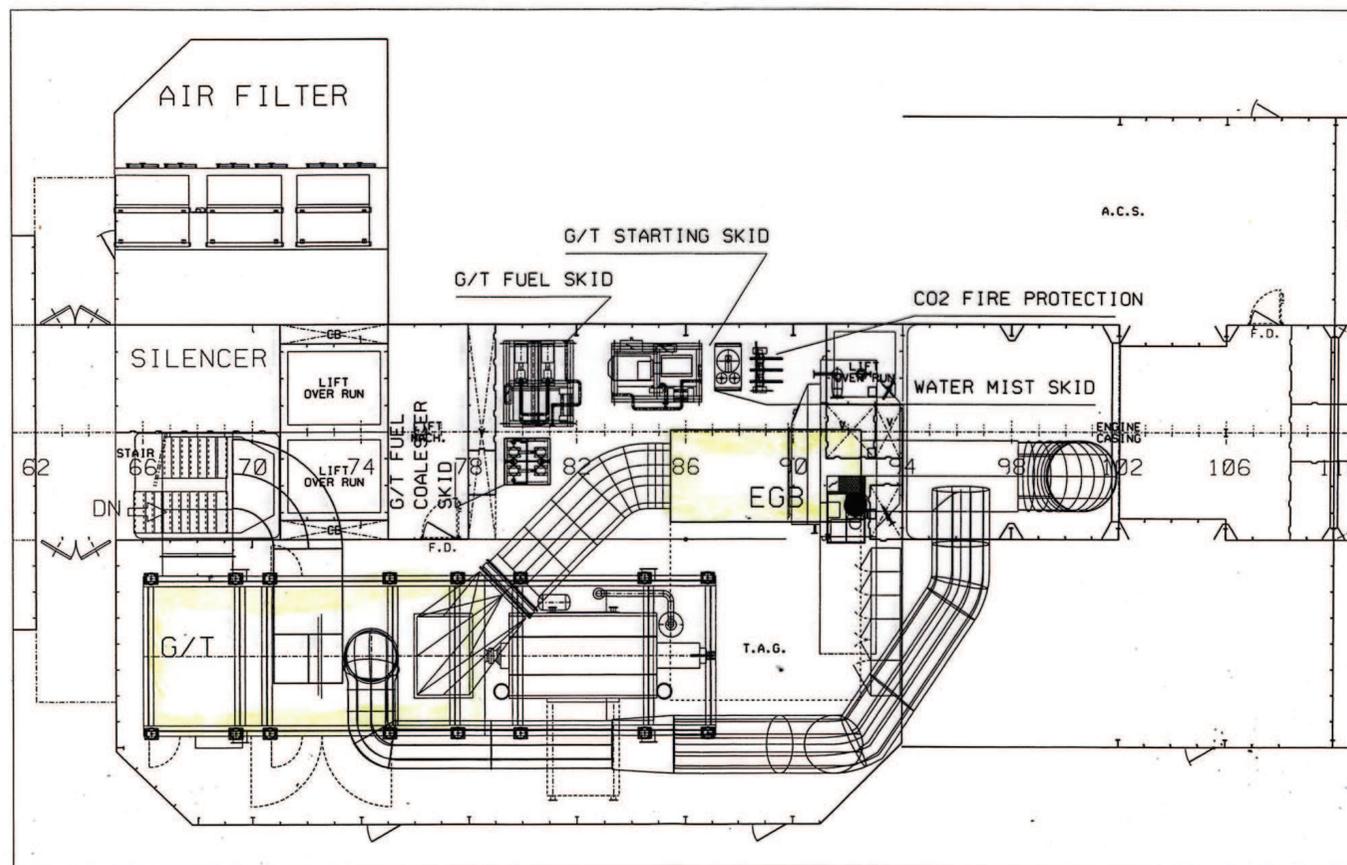
**The conclusion is that there is little need for a CODLAG machinery in conventional cruise ships. The diesel-electric plant can offer the lowest RTR.**

**If lowest possible emissions are desired, then the diesel-electric plant equipped with common-rail injection, DWI or SCR in combination with good fuel will be the best alternative. This machinery offers lower emission levels and better economic performance than both the COGES and the CODLAG machinery.**

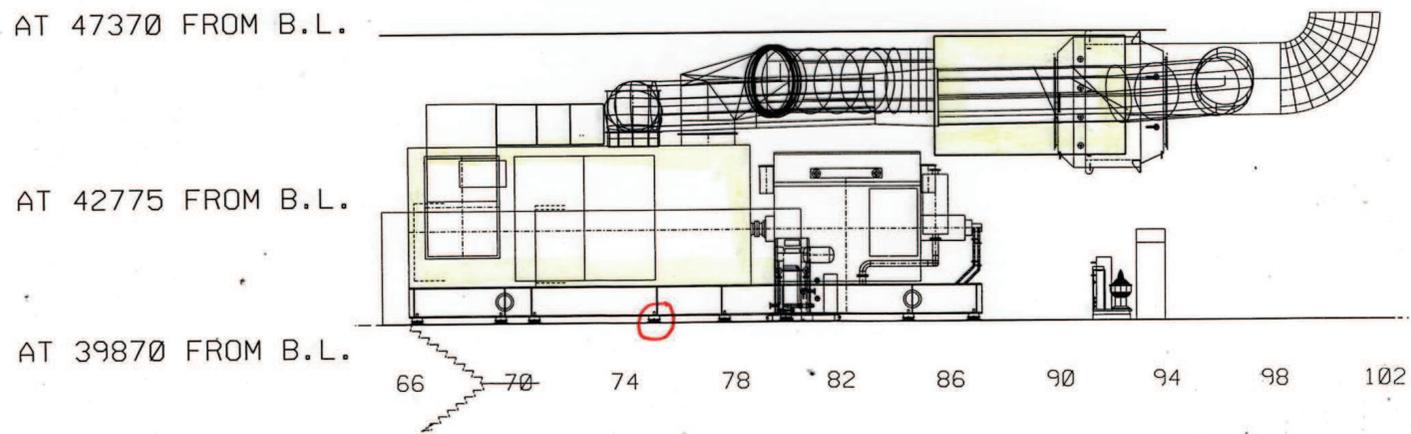
# Impianti di propulsione navale



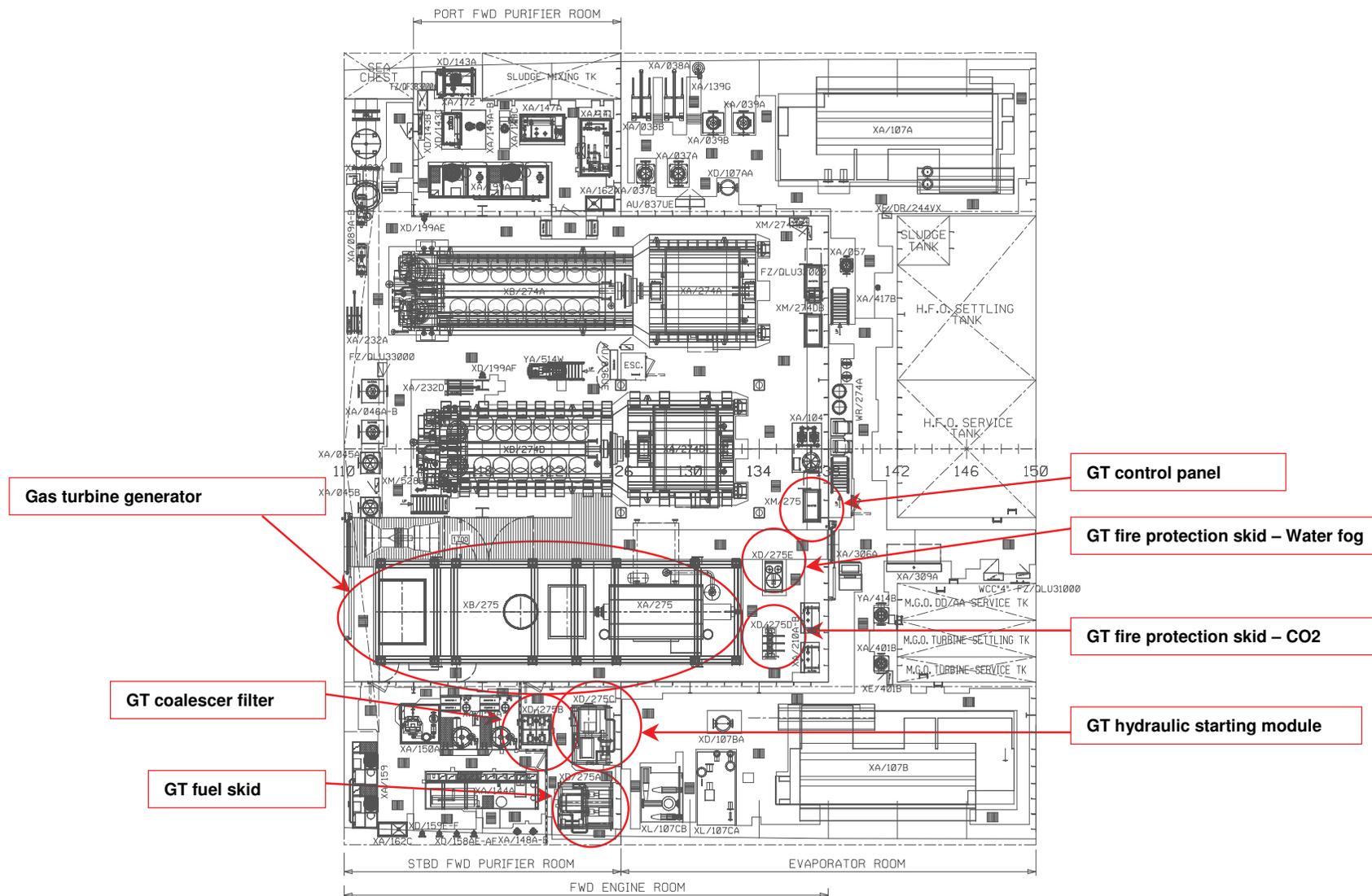
# Impianti di propulsione navale



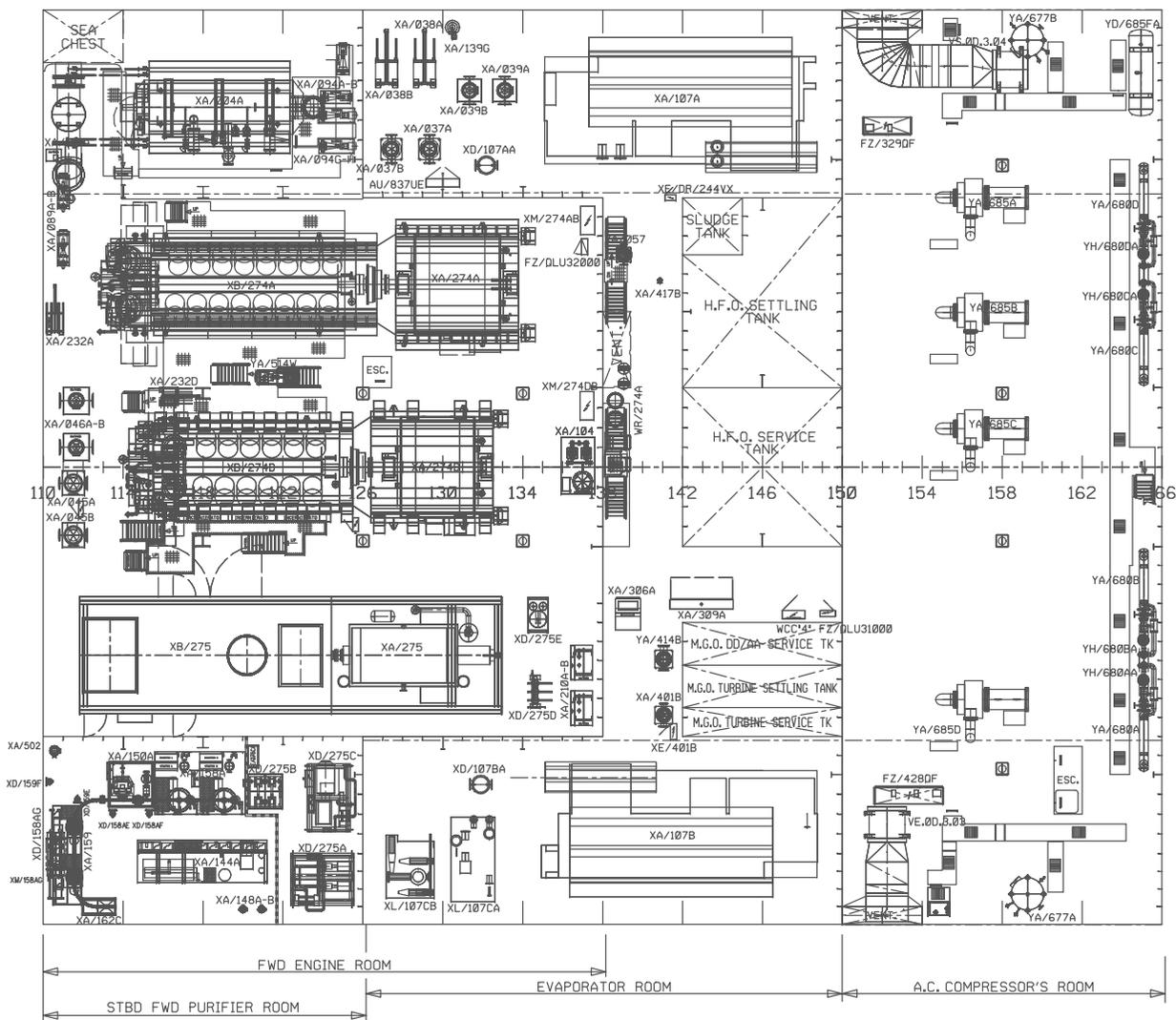
# Impianti di propulsione navale



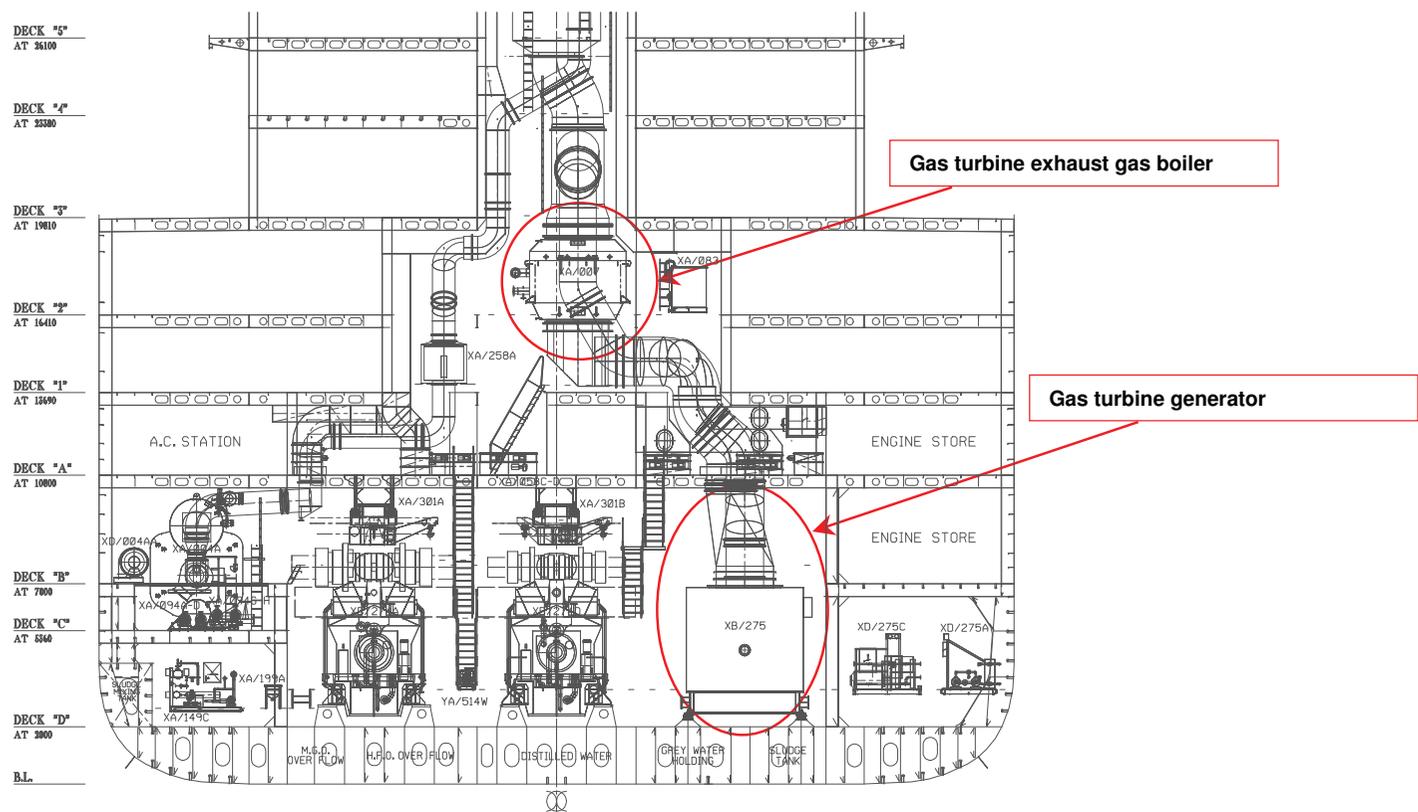
# Impianti di propulsione navale



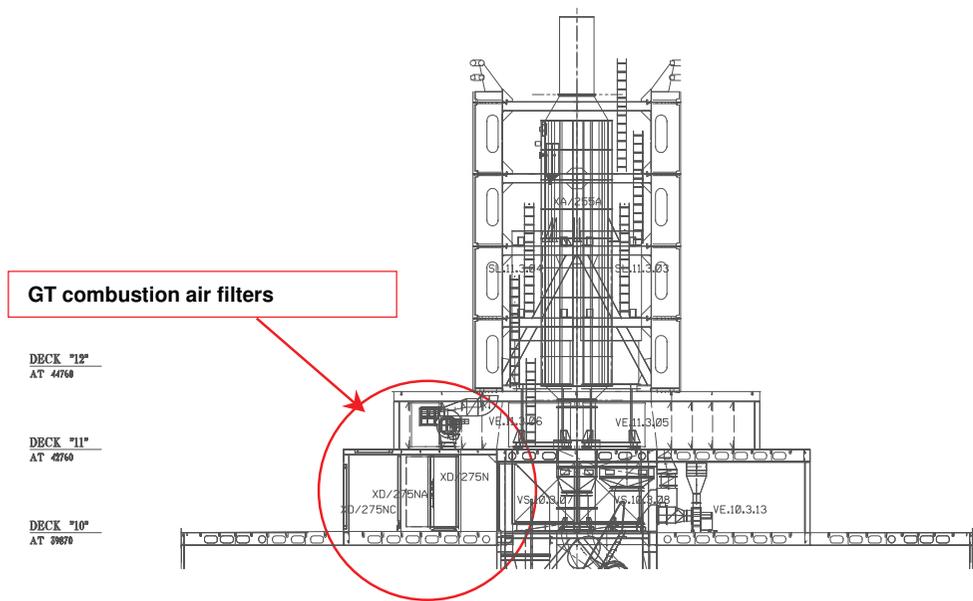
# Impianti di propulsione navale



# Impianti di propulsione navale



# Impianti di propulsione navale



# Impianti di propulsione navale

Plan at deck 10

