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A 21st CENTURY WARSHIP WITH A 21st CENTURY PROPULSION SYSTEM

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ABSTRACT

The Visby Class Corvette will enjoy the advantages of a Combined Diesel or Gas (CODOG) turbine arrangement in which the diesel engines are used for low-speed mine hunting and ASW missions, while the four turbines can be operated either individually or in pairs to provide cruise or high-speed dash capability. The integration of these features into a single gearbox, the design of the AlliedSignal model TF50A turbine engine, and the integration of the CODOG system into the ship is discussed herein. Attention is focused on the unique design features which provide the "stealth" capabilities of this ship.

NOMENCLATURE

ASW	Anti-Submarine Warfare
CIP	Component improvement program
CODOG	Combined Diesel or Gas Turbine
DNV	Det Norske Veritas
EMC	Electro-magnetic compatibility
EMI	Electro-magnetic interface
F-76	Diesel fuel
FADEC	Full Authority Digital Engine Control
FETT	First engine to test
FMV	Swedish Defense Materiel Administration
GT	Gas turbine
GTPMS	Gas Turbine Propulsion Module System
IR	Infrared
ITP	Industria de Turbo Propulsores of Spain
KkrV	Karlskronavarvet
LCAC	Landing craft, air cushion
LOP	Local operating panel
MRG	Main reduction gearbox
NATO	North Atlantic Treaty Organization
PLC	Programmable logic computer
RAM	Radar absorbing material
TF40B	AlliedSignal gas turbine engine
TF50A	AlliedSignal gas turbine engine
U.S.	United States

THE SWEDISH NAVY TODAY

During the last 40 years, the Swedish Navy has gone through considerable change. At the end of the Second World War, the Navy was a significant power with a large number of ships of various sizes. The smaller craft, like mine sweepers and torpedo boats, operated in or near the archipelago, where the threat was lower. The larger ships, mainly frigates and destroyers with Anti-Submarine Warfare (ASW) capability and sufficient air defense, had good survivability in the open sea.

In the 1960s and 70s as the air threat grew, the Swedish armed forces faced budget cuts. The Navy sustained the most significant disarmament. Larger ships were replaced with smaller, more efficient units with high striking power. The reduced size, however, made them more sensitive to weather in the open sea and dependent on nearby support.

Since 1980, the threat has continued to increase as missiles, torpedoes, and sensors have become more capable and intelligent. The cost of an effective warship air defense has increased dramatically. Furthermore, the threat scenario has become more complex, with conflicts at all levels and with many different participants.

To address the current military environment, the Swedish Defense Materiel Administration (FMV) and the Naval Staff have carried out studies to find new, cost-effective solutions. Stealth technology, combined with passive countermeasures, is well suited to this complex scenario, in which it is hard to know who is the enemy and who is not. With a strong passive self-defense, it is possible to operate in a hostile environment without an active, first-strike capacity as the main choice.

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STEALTH DEVELOPMENT

The concept of stealth technology includes everything that minimizes signatures and signals, to hinder identification and prevent detection, while increasing the efficiency of countermeasure systems and sensors.

The first effect of reduced signatures is increased performance of a vessel's own sensors, which is gained as a result of decreased noise-levels.

Going further, the next effect is increased performance of the vessel's own passive countermeasure systems. This level of performance is achieved when the vessel's reflected or transmitted energy is substantially lower than that of the countermeasure systems.

At the next level, the aim is to achieve signatures so low that, even if it is possible to detect the ship, identification is difficult.

The highest-level stealth technology is to completely avoid detection. To reach this state, signatures must be about the same level as, or lower than, the environmental background noise. On all levels, but particularly on the highest, environmental factors such as weather and operational area are of great importance.

On the Visby Class Corvette,[1] actions have been taken in all stealth areas (Figure 1) in the air as well as under the water. The goal is to achieve maximum effects at all levels, including the highest one as described above. Table 1 lists the elements of stealth technology used on the Visby Class Corvette and their effects.

Table 1. Elements of Stealth Technology.

Signatures	Measures	Effects
Radar	Optimization of hull form and hull materials. Equipment, weapons, and sensors are specially designed or placed under hatches or RAM (Radar Absorbing Material)	More effective air defense, shorter detection /identification range, simpler/cheaper countermeasures, tactical advantages
IR and optical	Optimization of hull materials and paint, concealed exhaust and ventilation emission outlets, water spray, camouflage actions	More effective air defenses, shorter detection range, tactical advantages
Hydroacoustic	Silent water jet propulsors, low-speed machinery and generators double-elastically mounted inside noise hoods, noise-producing equipment mounted according to special instructions	Shorter detection range, increased performance of own sensors, tactical advantages
Magnetic	Optimization of hull materials, equipment demagnetized as far as possible, degaussing system	Shorter detection range, more difficult for detonation of mines
Transmitted Signals	Passive sensors, sectored transmissions, tactical adaptation	Obstructs reconnaissance, obstructs signal seeking weapons

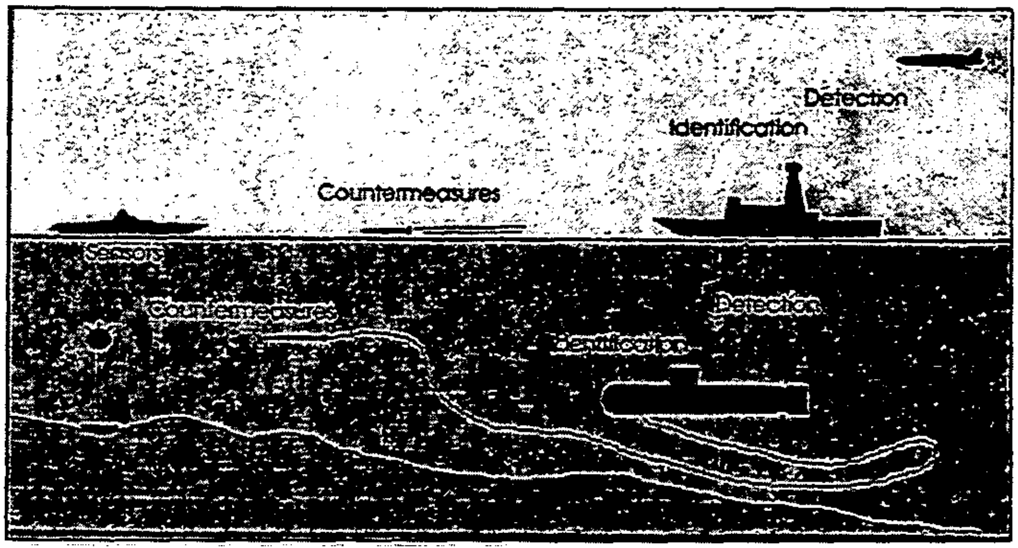
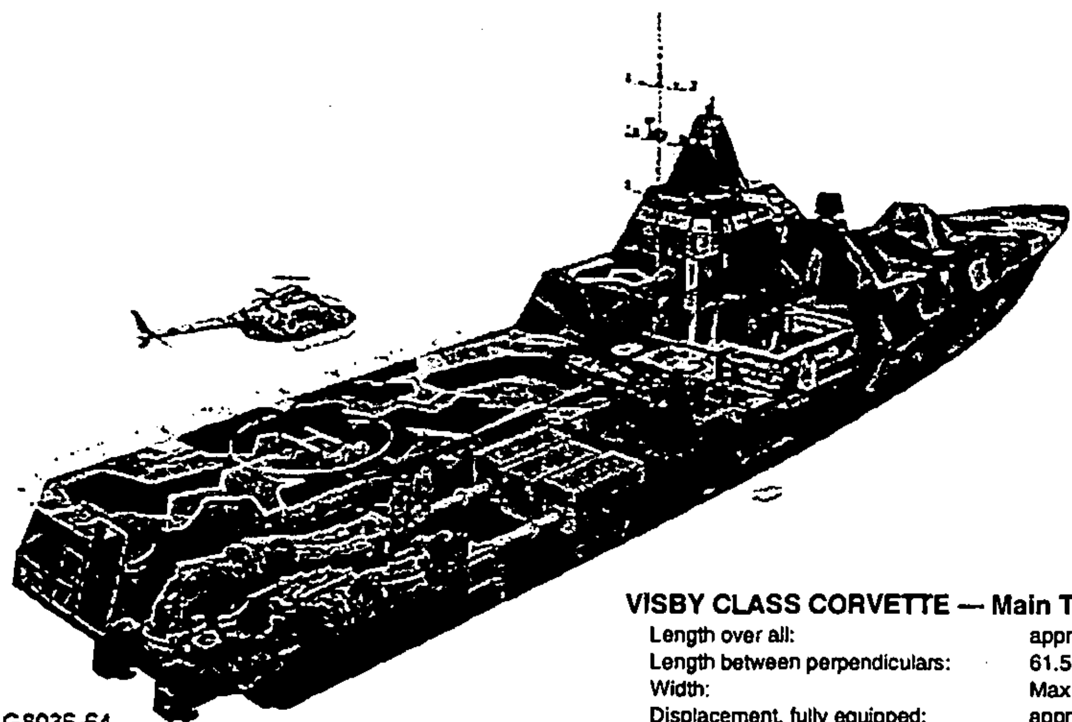


Figure 1. Naval stealth can be achieved at all levels.



VISBY CLASS CORVETTE — Main Technical Data:

Length over all:	approx. 72 m
Length between perpendiculars:	61.5 m
Width:	Max 10.4 m
Displacement, fully equipped:	approx. 600 tons
Draught:	approx. 2.5 m
Crew:	43
Hull:	FRP-sandwich
High speed machinery:	4 Gas Turbines, total approx. 16,000 kW
Low speed machinery	2 diasal engines, total approx. 2,600 kW
Propulsion:	2 water jet propulsors
Ganarators:	3 generators, total approx. 810 kW

Figure 2. View of the YS2000.

MONOHULL MULTIPURPOSE COMBAT SHIP

The design of the YS2000 Visby Class Corvette integrates many features to achieve the lowest possible signatures for maximum stealth. The hull has large, flat surfaces and sharp edges, as shown in Figure 2.

The vessel has a built-in cargo deck, considered a novelty on such a relatively small vessel, which gives many advantages. The first is a weather-protected working area that allows for great endurance and the opportunity to carry out missions in rough weather. The ship's armaments are concealed, making it impossible for an observer to determine its mission. The ship's signatures, above all its radar cross section, have been strongly reduced without extensive cost-increasing measures being taken on the installed equipment.

A helicopter can take off, land, and refuel on the upper deck; and preparations have been made for installing a hangar on the ship. The hull has been built for optimal seagoing qualities and course stability without compromising maneuverability. It is specially designed to suit water jet propulsion.

Propulsion Machinery

The ship is equipped with COmbined Diesel Or Gas turbine (CODOG) machinery, with four AlliedSignal TF50A gas turbines for high speed and two MTU Series 2000 diesel engines for low speed, connected to two gearboxes which power two waterjet propulsors. This allows speeds of up to 15 knots in silent mode and a top speed of more than 35 knots. As a complement to the waterjets, the ship is equipped with a bow thruster for harbor maneuvering.

New technical solutions give low noise radiation internally, externally, and hydroacoustically; the generators and low-speed diesels are mounted double elastically inside noise enclosures. Special stealth features associated with the turbine engine system will be described after discussing the development of the TF50A engine. The system provided by AlliedSignal, which is referred to as the Gas Turbine Propulsion Module System (GTPMS), is shown in Figure 3. It consists of two TF50A turbine engines directly mounted to a Cincinnati Gear Main Reduction Gearbox (MRG), a Local Operating Panel (LOP), and an inlet system. The MRG also has an input pad for the diesel engine. Two GTPMS CODOG systems are installed in parallel on the ship to drive two separate water jets. Each GTPMS CODOG system provides power to a KaMeWa Series 125 water jet via a propulsion shafting system consisting of two separate shafts. One shaft runs between the diesel engine and MRG, and the other one is between the MRG and water jet. Both shafts will be made of a composite material. The four gas turbines can be operated individually or in pairs, or the diesel engines may be operated. The GTPMS is not designed for continuous operation of a diesel and the turbine(s), but is only intended for transitioning from one to another. The development of the TF50A engine and the GTPMS system for this ship are currently underway, as described in the following sections.

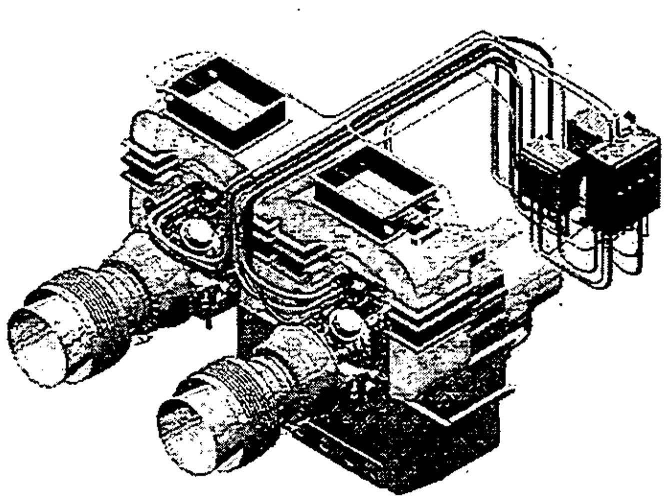


Figure 3. GTPMS for the YS2000.

TF50A ENGINE BACKGROUND

The AlliedSignal TF50A turbine engine is a commercial derivative of the Enhanced TF40B engine being upgraded for the U.S. Navy Landing Craft, Air Cushion (LCAC) and a risk/revenue-sharing arrangement for development of an improved power turbine with ITP of Spain. The gas turbine arrangement, with the relative improvements of each component, are shown in Figure 4.

LCAC Enhanced TF40B Marine Gas Turbine Program

The Enhanced TF40B Program, referred to as the ETF40B, is the result of almost 15 years of continuous operation and over a quarter million engine operating hours on the U.S. Navy LCAC. This design incorporates improvements to specific components which have been identified over this long operating period.

The original TF40B engine was selected by the U.S. Navy in 1982, based on its commercial off-the-shelf design and solid dependable reputation. At that time the marine experience of the TF Series of engines was more limited, and the U.S. Navy required a 1000-hour endurance test in accordance with MIL-E-17341.[2] The results of this test indicated that when operating at high power on NATO F-76 diesel fuel, the combustor created erosive carbon particles. These particles slowly flattened the leading edge of the first turbine wheel and cut a small hole at the leading edge base of the second. This result was of particular importance to the U.S. Navy, since the world-wide deployment requirement mandated the use of many grades of fuel. Component Improvement Program (CIP) funds were applied to this problem resulting in an upgraded multi-fuel combustor liner which is in production today. Today, the U.S. Navy continues to operate the LCAC in one of the harshest salt- and sand-laden environments of any operational craft.

Over the extended operating period of the LCAC, several areas in which improvements are desired have been identified. As configured today, the TF40B engine does not have a customer bleed air port. When operating in cold environments, a special "kit" is fitted to the LCAC which uses engine exhaust air to heat the inlets to prevent ice build-up, but this causes early replacement of the "last chance" filter stage Also, the exhaust gasses are more corrosive to the engine than the normal salt environment. Compressor blade corrosion is one of the leading causes of Gas Producer Module removals. Other CIP tasks have been identified, for improvements to the electronic control box, ignition system, bearings, seals, and fuel valve/actuator. Many of these tasks have completed development, but funds have not been sufficient for incorporation. The Enhanced TF40B Program provides an opportunity for the incorporation of all of the above changes.

The U.S. Navy has a keen interest in the success of the Enhanced TF40B engine. The addition of variable compressor geometry has finely tuned the compressor, to increase the power and create useable customer bleed air. That addition alone on the LCAC will eliminate the heavy cold weather kit and the extra maintenance associated with its use. Also, the bonus of the variable geometry will enable the LCAC to perform the same mission at much higher ambient temperatures than with the current TF40B. The compressor blade coatings chosen during the CIP will significantly reduce the corrosion to this section of the engine. The Full-Authority Digital Engine Control (FADEC) will provide a reliable, tamper-resistant control system which will interface with the new digital control system on the LCAC. A proven, reliable high-tension ignition system will replace the current system which requires periodic ignitor plug replacements. The resulting conversion kit will permit the U.S. Navy to upgrade the existing TF40B engines to the enhanced configuration, while retaining a large percentage of the original engine equipment. Most importantly, the sum of all these improvements will reduce both direct operating costs and fuel consumption, which provides a payback to the U.S. Navy for the initial investment cost of incorporating the upgrade kit.

Development of the TF50A

Design and development of the Enhanced TF40B engine began in the spring of 1996 under a contract with the U.S. Naval Sea Systems Command. Taking this process one step further, the TF50A engine adds a redesigned power turbine to the enhancements of the TF40B. The upgrades and enhancements required by this program are illustrated in Figure 5.

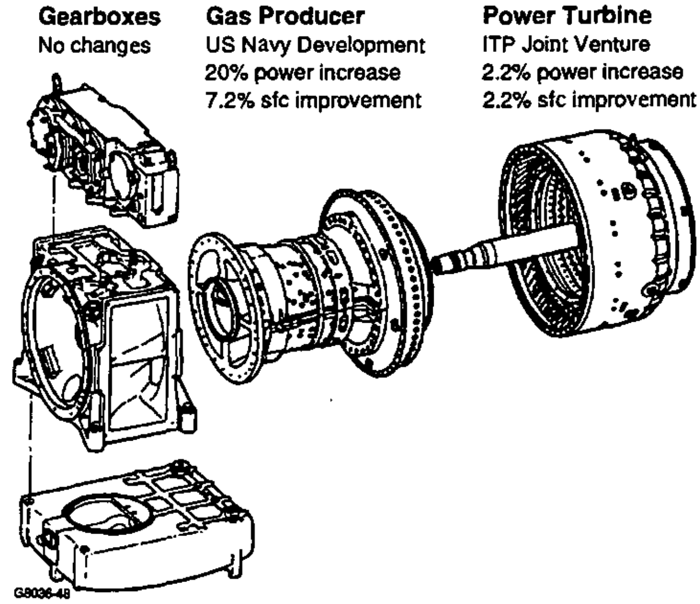


Figure 4. Enhancements to TF40 that define TF50A engine.

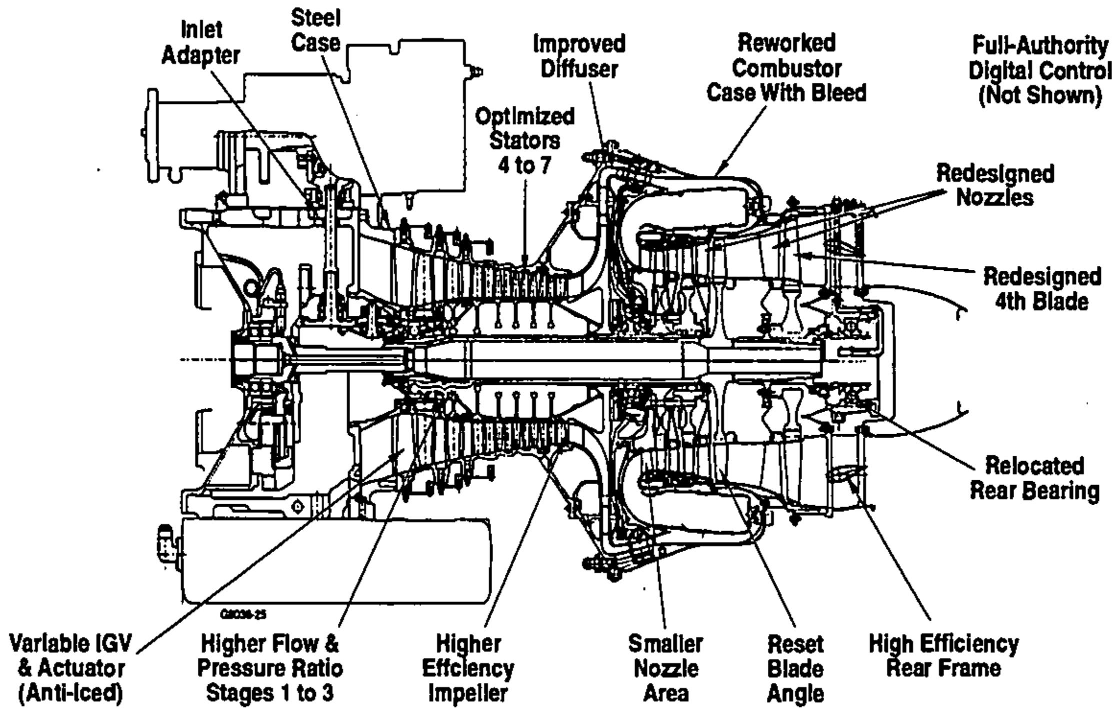


Figure 5. Engine core enhancements and upgrades for the TF50A.

The TF50A test program began with compressor rig testing to verify the analytical performance calculations for the compressor section of the engine. The first series of tests demonstrated that the compressor was producing 2% more flow at 1% higher efficiency than expected.

Upon completion of the compressor rig testing, the rig hardware was rebuilt into a complete engine assembly to form the First Engine To Test (FETT). Since this engine used the same hardware as in the compressor rig test, it was also heavily instrumented. Over 600 pressure and temperature sensors were active during the initial runs of this engine, shown in the test cell in Figure 6.

The results of the FETT engine runs showed that the engine continued to produce more air at a higher pressure ratio than analytically predicted.

The FETT engine was specially designed to provide a wide range of motion in the guide vane system. This engine contained four stages of variable stators, as opposed to the three stages planned for production. This additional stage provided the opportunity to optimize the last-stage geometry prior to fixing the angle for the production engine.

In addition, each stage was made individually variable, again permitting the optimization of each stage for various operating conditions. The production engine will use only one actuator to move all three variable stages, through a combined set of linkages and unison rings.

The control system for the FETT engine was a programmable logic computer (PLC) which could command each stage of the variable geometry independently. The production engines will use a Full Authority Digital Engine Control (FADEC). This control system was developed independently from the FETT engine and in fact, the FADEC was running the TF40B engines prior to the FETT engine first run. This provides confidence in the control laws of the FADEC, and will simplify the transition from the PLC to the FADEC.

A second engine build has been completed, and the TF50A engine is continuing in the development program. Development testing is planned to continue through the end of 1998. Strain gage testing of the compressor will be completed to verify analytical results and to verify the vibratory modes of the compressor. Development testing of the ITP turbine section will begin during the summer, and then will be mated to the compressor improvements later in the fall of 1998. Endurance testing will continue throughout this period, with the goal of proving the basic engine design. Upon completion of the development testing, a 150 hour model derivative test of the TF50A configuration engine will be initiated to demonstrate compliance with MIL-E-17341. The combination of the above testing, plus additional EMI/EMC testing at Karlskronavarvet (KkrV) will lead to both military certification of the Enhanced TF40B and Det Norske Veritas (DNV) classification of the TF50A.

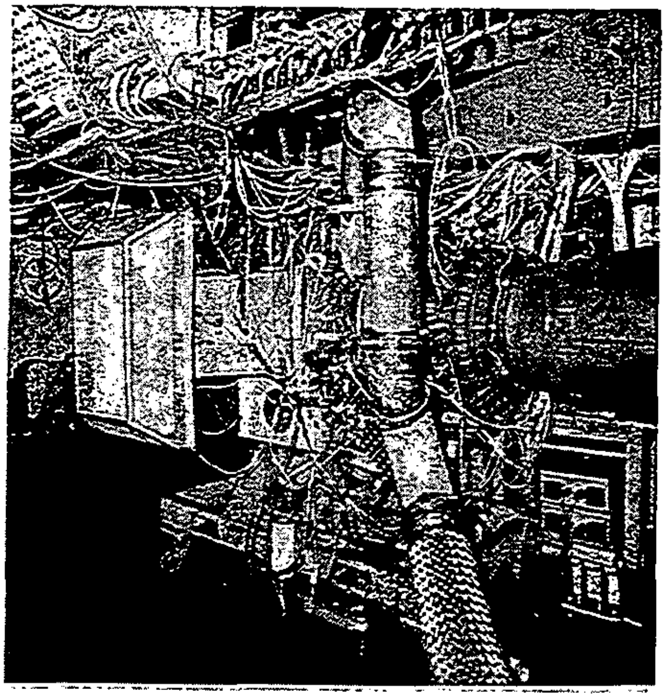


Figure 6. Testing of enhanced TF40B FETT.

GAS TURBINE PROPULSION MODULE SYSTEM AND STEALTH CAPABILITIES

Each GTPMS for the Visby Class includes the two TF50A engines (which have already been discussed above), the main reduction gears (MRG), an inlet duct system, the LOP/FADEC/Controls interface to the ship, fire protection, and exhaust systems. The Visby includes two complete GTPMS units.

Main Reduction Gearbox

Cincinnati Gear Company of Cincinnati, Ohio is providing the MRGs for the Visby ships. The MA-107 SBS is a high-speed marine CODOG reduction gear unit. This reduction gear provides main propulsion for the vessel. The gearbox has three power inputs: two AlliedSignal TF50A gas turbine engines and one MTU Series 2000 diesel engine. All of the inputs are combined into one output shaft that drives a KaMeWa size 125 waterjet. The reduction gear is rated for 8,400 kW during turbine mode and 1,300 kW during diesel mode.

Several design features have been incorporated into the GTPMS to minimize structure-born sound transmission to the ship's hull and to meet the stringent shock requirements of the Visby:

- The two TF50A engines are cantilever mounted to the main reduction gearbox without using aft supports. This mounting method reduces the number of possible vibration transmission paths to the GTPMS-to-ship mounting structure.
- To meet the shock requirements with the engines cantilever mounted to the gearbox, the TF50A engines have been modified specifically for the Visby application, by increasing the number of engine-to-gearbox attachment bolts and by using special hardware to increase the flexibility of the engine mounting scheme.
- AlliedSignal, Cincinnati Gear and Karlskronavarvet are collaborating on the design and analysis of the entire GTPMS mounting system, which will be a cradle that interfaces between the MRG and ship structure. The cradle will isolate the propulsion system from emitting any detectable signature and also protect the propulsion system from environmental shock. An in-depth analysis and test program has been designed to ensure the propulsion system meets all of the unique stealth environmental requirements of the Visby.

Air Inlet System

The combustion air inlet is a part of the ship structure, with the inlets mounted on the side of the ship. There is a separate air inlet system for each GTPMS, with air ducted from the atmosphere via a low radar signature screen and through a three-stage water-separating filter down to each TF50A engine. Blow in-doors are located adjacent to the radar screen and the three-stage filter, which will open automatically via a signal from a differential pressure sensor if ice causes a severe restriction. The inlet system has actuated louvers above each engine to terminate airflow when a gas turbine (GT) is not running. The GT inlet ducting also includes safety screens and flexible sections for minimizing structure-borne sound transmission and to allow for relative movements.

Control System

Operation of the GTPMS is performed with the control and monitoring system. Each TF50A gas turbine is controlled by a FADEC, and the MRG is controlled by a separate digital control Main Reduction Gearbox Control (MRGC). The Gas Turbine Local Operating Panel (GT LOP) communicates with each FADEC, the MRGC, and the ship control system using both an analog and serial communication links. The GT LOP also provides an interface for the operator in the engine room and for operators at other ship locations. The GT LOP also monitors and controls the other GTPMS and ship systems required to start, stop, and safely operate the GTPMS. These auxiliary systems include the air inlet louvers, ship fuel boost pumps, and ship fuel shutoff valves. A block diagram of the GTPMS control system is shown in Figure 7.

Each gas turbine can be independently controlled from any of the ship control stations: Engine Room, Engine Control Room, or Bridge. The control system allows for control and monitoring of the

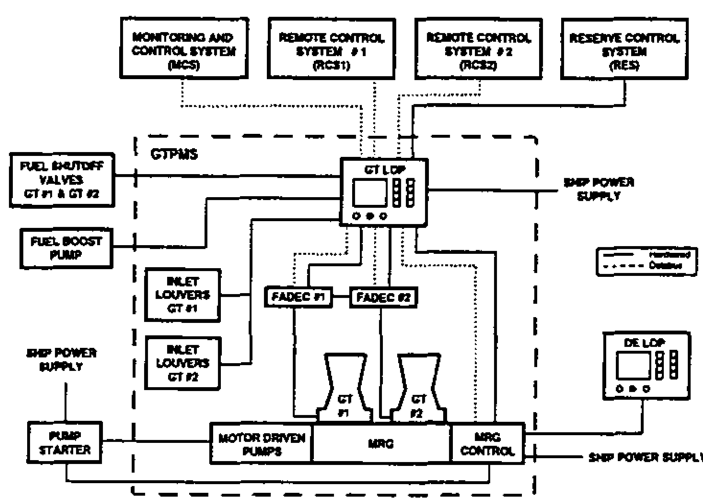


Figure 7. Control System Diagram

GTPMS in three modes: RCS1, RCS2, and Reserve, and two control locations (local at the GT LOP, and remote at all other ship control stations). The Main control mode involves control and monitoring of the GTPMS using serial-communication-based data signals sent between the GTPMS and the ship Remote Control Systems (RCS1 and RCS2). The Reserve control mode involves control and monitoring of the GTPMS using hardwired analog signals between the ship and the FADECs, and MRGC. All of GTPMS safety systems are incorporated in the LOP, FADECs, and MRGC to ensure that operation of the gas turbines and MRG are within the design limits.

Exhaust System

The exhausts from the Gas Turbines are combined into one exhaust pipe and ducted through the vessel to the transom of the ship. The exhaust outlets are concealed above the Water Jets and ducted downward toward the jets and the water. The exhaust system will be provided with a water-injection IR suppression unit. During higher speed operations with the turbine engines, the goal is to conceal the exhaust in the depression caused by the ship's stern wave. The exhaust pipes are flexibly mounted and insulated for reducing the sound transmission and maintaining a human-friendly environment onboard the vessel. A view of the entire installed system including the exhaust ducts is shown in Figure 8.

Fire Prevention / Noise Suppression

The hot section of each engine will be covered with a cylindrical enclosure that performs two functions: it is primarily a fire zone in the case of an engine fire, and it also provides additional acoustic treatment to lower the noise in the engine room. This noise affects not only personnel who might be transient in the engine room, but also lowers transmitted noise through the ship's structures and hull.

GTPMS Reduction / Magnetic Signature

The magnetic signature of the GTPMS, and especially of the MRG, is reduced for the magnetic steel parts such as the gear wheels, shafts, etc. by demagnetizing ("de-perming") before assembly of the gearbox. Before installation of the GTs and MRG in the ship, they will be de-permed as assemblies. An active degaussing system will also be installed around the MRG for reduction of the magnetic signature while onboard.

Waterjet Characteristics

The waterjet unit for the Visby Class Corvette will have special solutions for stealth and is being specially developed for this project. The special solutions are for reducing the hydro-acoustic signature, and accommodating parts made of composite materials that will weight optimize the unit as compared to standard waterjet units.

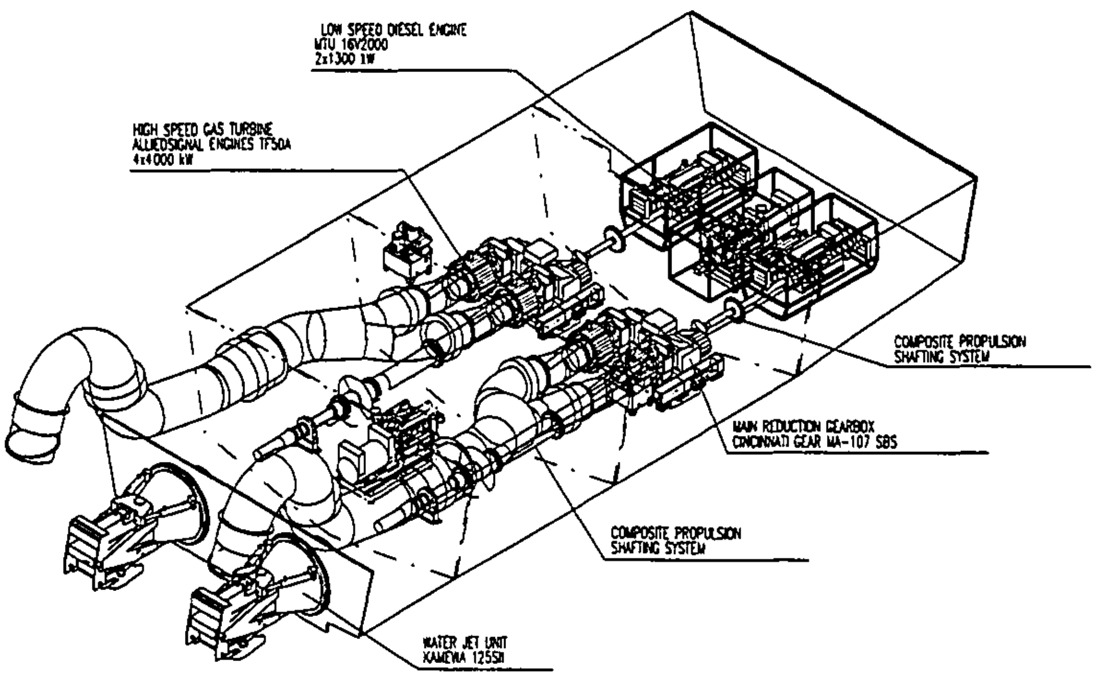


Figure 8. Visby Class propulsion system installation.

PROJECT STATUS TODAY

Contracts have been signed between the FMV and the KkrV for the construction of the first series of ships. The hulls for the first ships are under construction at KkrV. The GTPMS contract has been signed and the TF50A engines and MRG are in development, with an expected delivery date of the second quarter, 1999.

The first series consists of four ships, with a second series planned. The ships will be commissioned at the beginning of the next century and are expected to have a lifetime of 25 years.

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