FUTURE MARINE GAS TURBINES

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ABSTRACT

The article gives an overview of the way in which next generation marine gas turbines are likely to develop by utilizing Complex Cycle features. This approach will result in reduced cost of ownership, primarily through the route of improved specific fuel consumption. Examples of current applications and future developments are described.

Introduction

The Royal Navy operates four different Rolls-Royce aero-derived marine gas turbines for main propulsion duties. These engines (Tyne, Olympus, Spey SM1A and SM1C) are all twin-spool simple cycle gas turbines of varying maturity in the marine environment. As the marine designs have progressed through first generation Tyne, Olympus to Spey SM1A and now third generation Spey SM1C, the engines have achieved lower fuel consumption characteristics and benefited from many detail design improvements to increase engine life and reduce cost of ownership.

The emphasis on reduced costs is a continuous process and the next logical step, given the difficulties of further significant improvement of simple cycle engines, is to move to complex cycle gas turbines. The benefits of this approach were recognized in the Royal Navy many years ago and two Rolls-Royce-designed RM60 5000 SHP complex cycle gas turbines (FIG. 1) were designed, built and fitted in HMS *Grey Goose* and went to sea in 1953.

Unfortunately, given the state of materials and gas turbine design technology at that time, many of the potential benefits could not be realized and the RM60 was unduly complex, large and expensive for the gains in lower fuel consumption that resulted.

What is a Complex Cycle Gas Turbine?

The principal differences between a complex cycle gas turbine and a simple cycle gas turbine are shown in FIG. 2. The complex cycle machine results from the incorporation of one or more additional features to improve the overall cycle efficiency. The principal changes normally consist of an InterCooler and a Recuperator—hence the term ICR cycle. In addition the part-load efficiency and dynamic response of the machine can be further improved by the use of a variable area power turbine, i.e. with movable power turbine stator blades.

The intercooler and recuperator are heat exchangers. The intercooler reduces the temperature of the compressed intake air to increase its density and thereby improve volumetric efficiency of the HP compressor. The recuperator recovers waste exhaust gas energy to preheat air entering the combustion chambers, which in turn reduces the combustion fuel requirements. The ability to fit an intercooler depends on the gas turbine being either:

(*a*) two-shaft with axial/radial compressor;

or

(*b*) single-shaft with two stages of radial compressor.

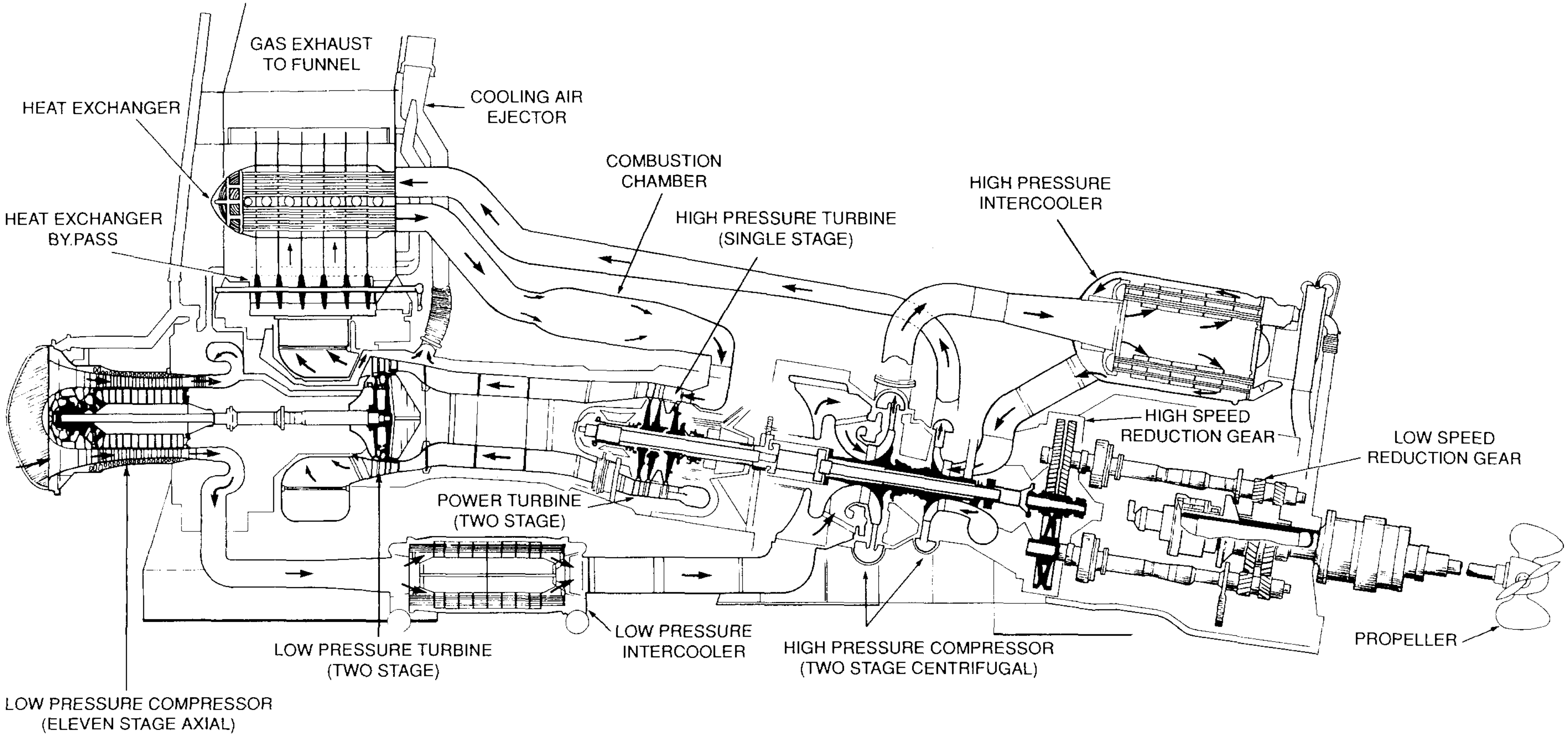

FIG. 1—ROLLS-ROYCE RM60 GAS TURBINE

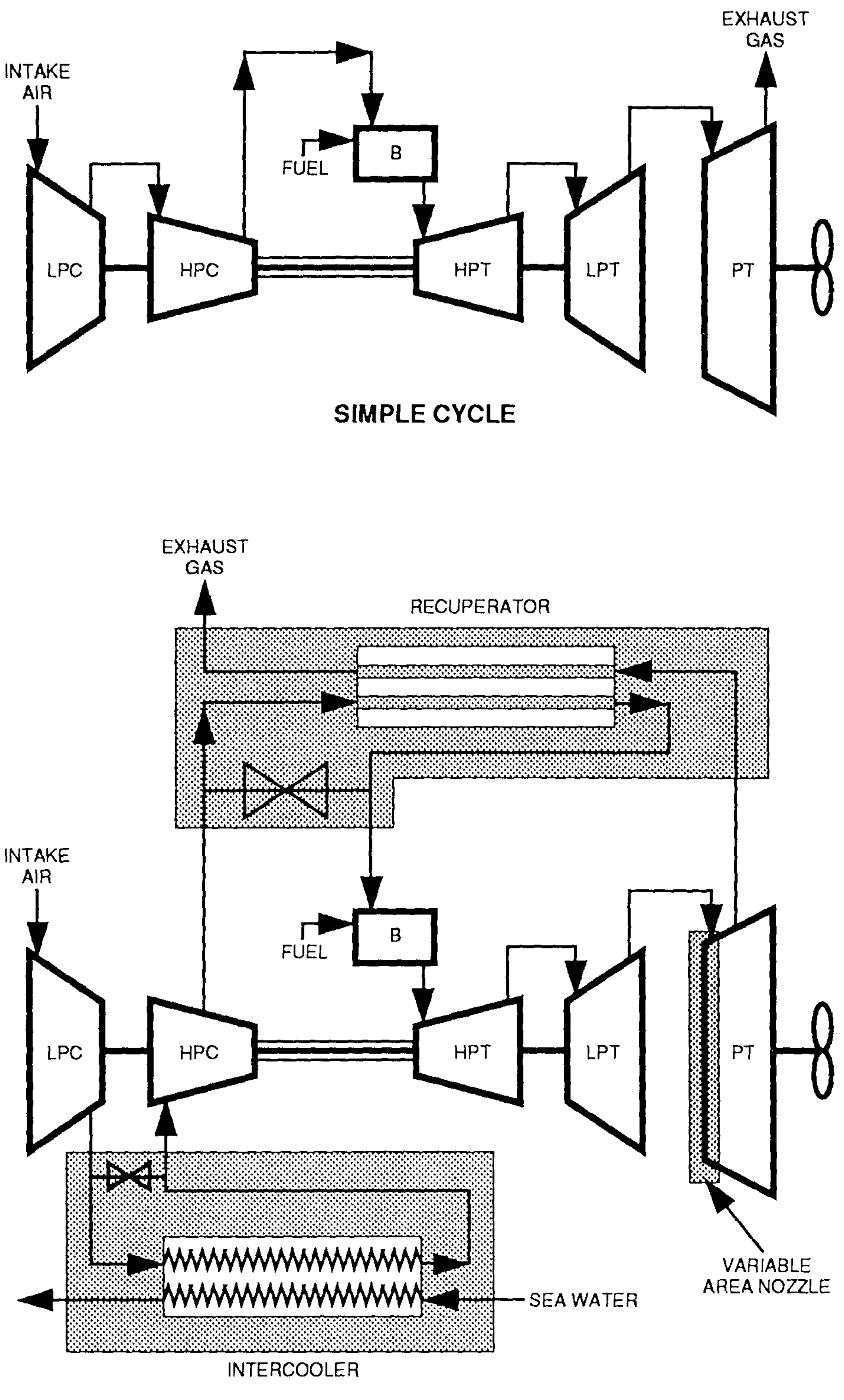

FIG. 2—INTERCOOLED & RECUPERATED CYCLE VERSUS SIMPLE CYCLE
HPC: High Pressure Compressor
HPT: High Pressure Turbine
LPC: Low Pressure Compressor
LPT: Low Pressure Turbine
PT: Power Turbine

Comparison—Complex v. Simple Cycle Gas Turbine

The major differences between a complex and simple cycle gas turbine can be discussed under the following headings:

Specific Fuel Consumption (sfc)

The marine simple cycle gas turbine's sfc has improved significantly with development, such that the Spey SM1C gas turbine is approximately 30% more fuel-efficient than an Olympus at similar power outputs of 18 MW. The fully intercooled, recuperated gas turbine offers an additional sfc improvement of 20–30% on the SM1C. Adoption of Variable Area Power Turbines extends the power range over which the sfc gain can be obtained. TABLE I and FIG. 3 show typical efficiency and sfc improvements that are possible using the different complex cycle gas turbine arrangements.

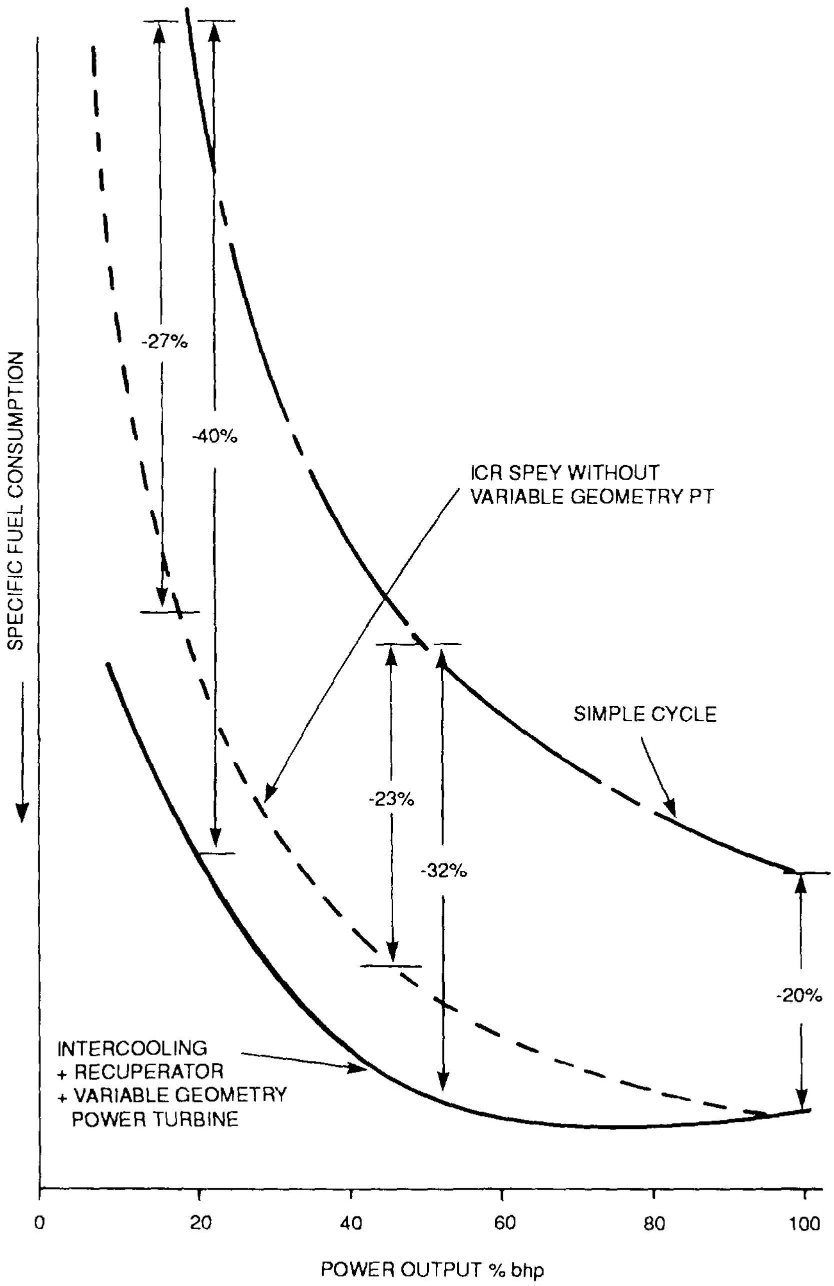

FIG. 3—PART LOAD SFC COMPARISON BETWEEN INTERCOOLED & RECUPERATED AND SIMPLE CYCLE GAS TURBINES

TABLE I—*Intercooled and recuperated gas turbines—summary of options*

	Maximum Efficiency	*Part Load*
Simple Cycle	35%	significant efficiency loss
Recuperated Cycle	40%	significant efficiency loss
Recuperated with Variable Power Turbine	40%	efficiency maintained down to 60% power
Intercooled and Recuperated with Variable Power Turbine	42%	efficiency maintained down to 40% power

Dynamic Response

Particularly for gas turbine driven electrical alternator duties the dynamic response of the gas turbine is important. Variable Area Power Turbines help to reduce the problem by altering the Power Turbine swallowing capacity to cope with rapid load changes.

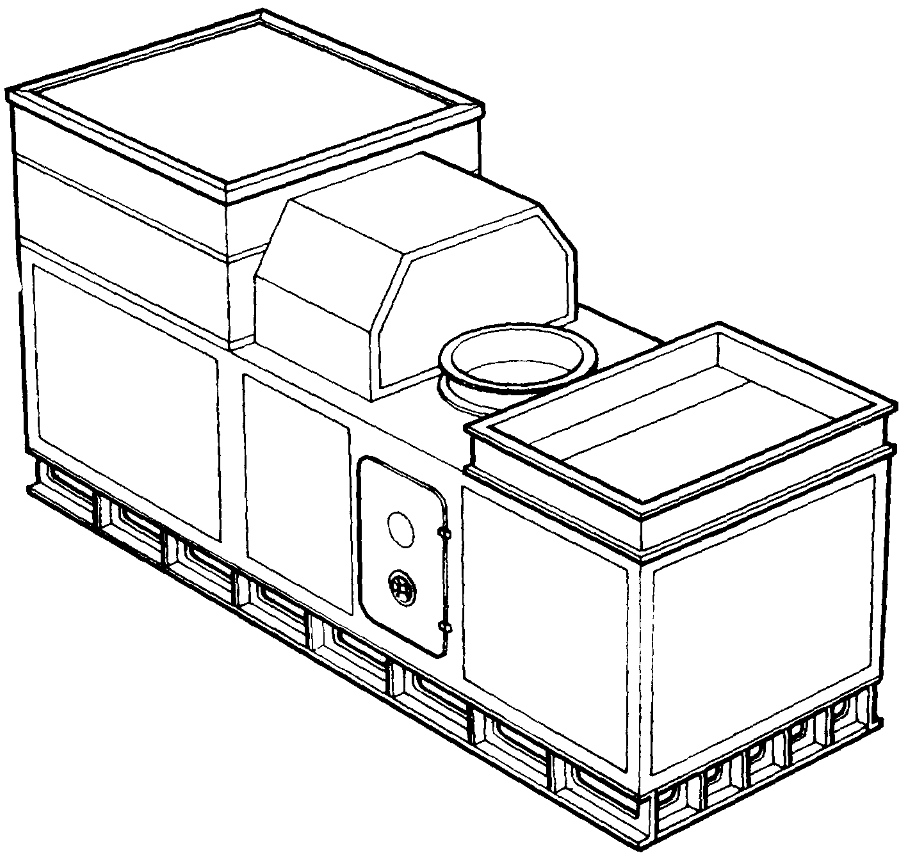

FIG. 4—ICR GAS TURBINE MODULE (8 m LONG)

Weight/Space

The complex cycle gas turbine is installed in a Module Enclosure (FIG. 4), similar in concept to the current marine gas turbine enclosures. The footprint would be no more than a simple cycle engine although weight and enclosure height would be greater because of the intercooler and/or recuperator.

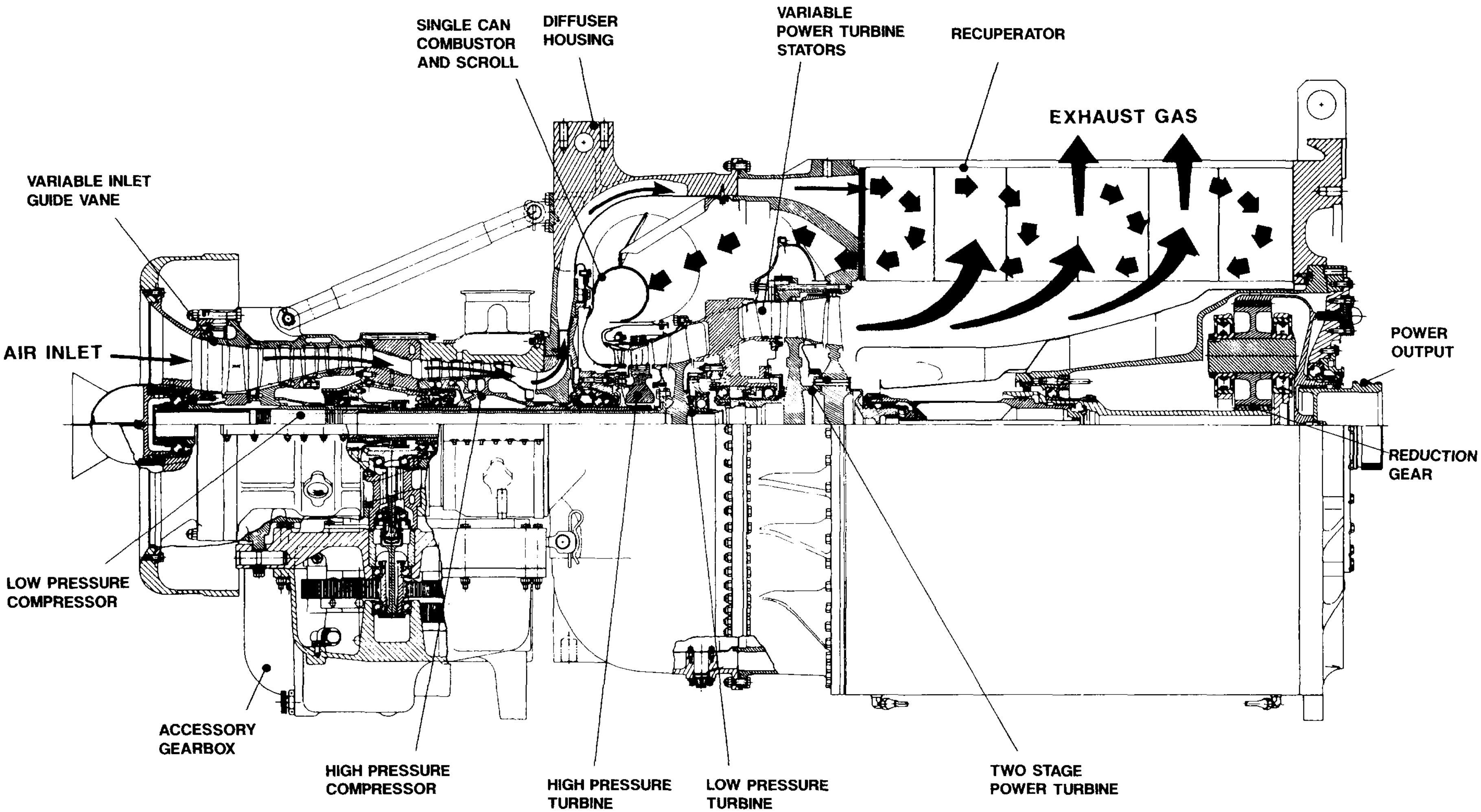

FIG. 5—TEXTRON LYCOMING TF15 TANK ENGINE

Cost

Unit Production Cost of a complex cycle engine is likely to be between 5% and 20% higher than that of similar power simple cycle gas turbines but this would be more than offset by the significantly lower fuel running costs over the life of the machine. For example the USN perceive a 30% fuel consumption advantage in moving from an LM2500 gas turbine to a modern ICR engine.

Maintainability

Much of the complex cycle gas turbine will employ familiar and well understood maintenance procedures. The main areas of difference will arise from any additional maintenance requirements introduced by the intercooler, recuperator and variable area power turbine. The intercooler is normally sea water cooled and as such is unlikely to present a significant or novel maintenance load. The recuperator will be essentially maintenance-free apart from regular bypassing to 'bake off' accumulated deposits, and the variable power turbine nozzle guide vanes may require occasional checking for correct calibration but should be a minimal demand on maintenance resources. Gas turbine change unit (GTCU) removal and replacement will be similar to current engines except for the requirement to disconnect/reconnect intercooler/recuperator ducting. Careful detail design in these areas will minimize the time and effort required to change an engine.

Risk

The area of highest technical risk is likely to be in the recuperator design although much work has already been carried out by specialists in this field.

Some development activity would be required for the intercooler and variable angle nozzles but neither represent a significant risk area. Sufficient work has been completed elsewhere to understand and analyse the risk elements of developing this type of gas turbine.

Current Applications

At present there are no complex cycle marine gas turbines in marine service. The US have made a major commitment to this type of technology with the Abrahams M1 tank engine which produces 1500 hp (FIG. 5). The engine is a Textron Lycoming TF15 fitted with a recuperator and saw extensive service in the Gulf War. To date over 10 000 engines have been manufactured.

The Future

Over the past few years a number of marine ICR gas turbine design concepts have been considered in the UK and USA. For some time a Rolls-Royce ICR Spey SM1A/SM1C was a candidate engine for a possible USN development programme, however an increased power requirement necessitated a change to an RB211-based ICR unit (FIG. 6). Rolls-Royce in partnership with Westinghouse has proved successful in winning a $160M development contract from the USN for a 26 500 SHP ICR marine propulsion unit. The advanced demonstrator programme consists of two engines and is due to complete by the end of 1995. The engine will be able to cope with a 10% power increase if required and return a 30% saving in overall fuel costs.

Studies have also shown the feasibility of a cruise power single spool gas turbine utilizing the HP spool of a Rolls-Royce Spey with variable area power turbine nozzles and a recuperator (FIG. 7). Such an engine would produce 5·4 MW and challenge the fuel consumption of an equivalent power diesel engine without any limitation on extended low power operation. This engine would be suitable either for direct drive through a reduction gearbox or for electrical generation where the variable area nozzles would allow a suitable dynamic response to cope with step electrical load changes.

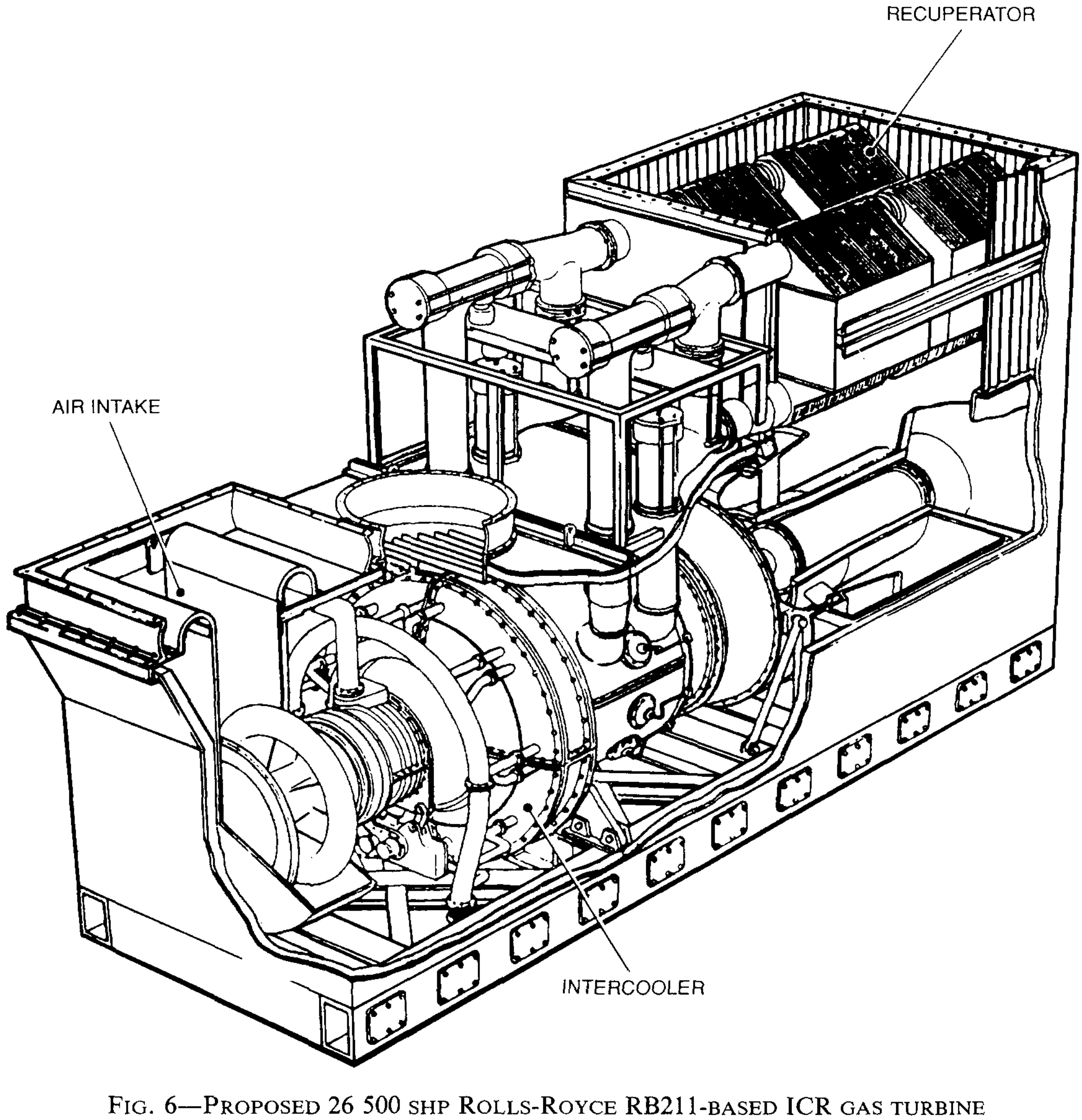

FIG. 6—PROPOSED 26 500 SHP ROLLS-ROYCE RB211-BASED ICR GAS TURBINE

Conclusions

The complex cycle marine gas turbine has real benefits to offer the operator in terms of reduced through-life cost of ownership compared with a simple cycle gas turbine.

The technology exists today to design, develop and build complex cycle marine gas turbines for either cruise or boost duty in future warship designs.

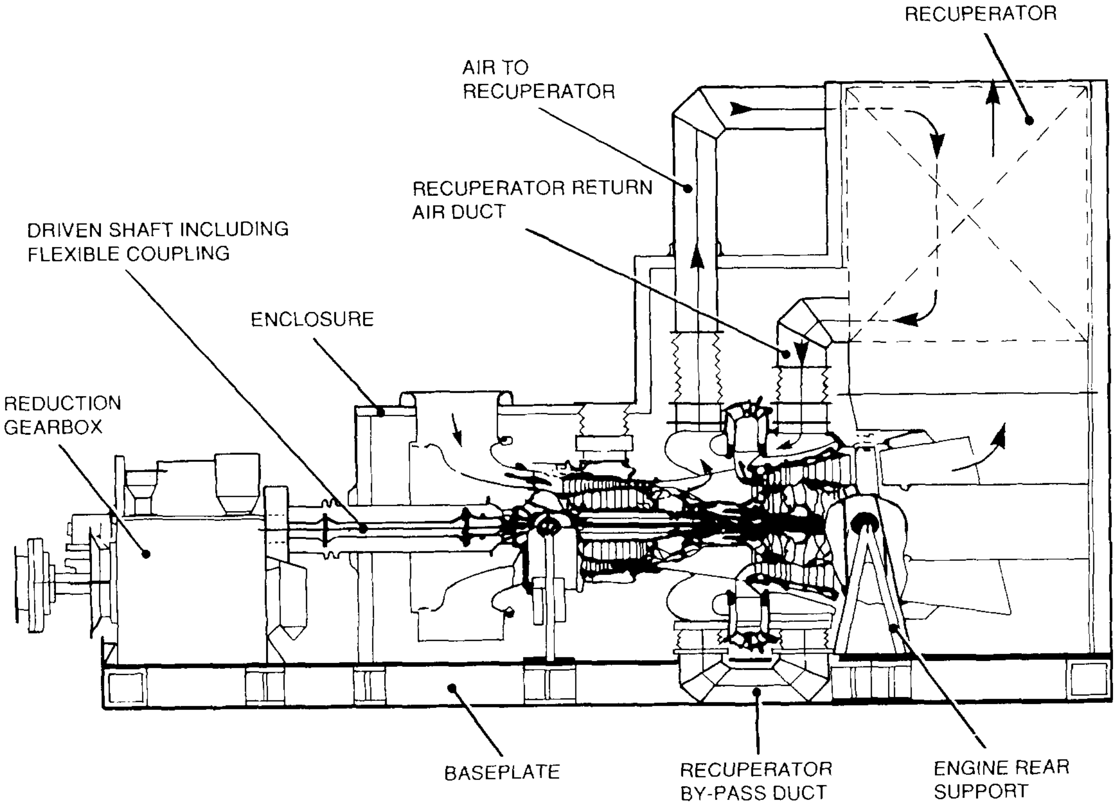

FIG. 7—SPEY-BASED SINGLE SPOOL COMPLEX CYCLE 5.4 MW GAS TURBINE