The Design and Development of the Orenda OT-4 Gas Turbine

P. A. Pitt

Mr. Quan's paper on the OT-4 gas turbine is highly interesting and informative.

It is of special interest to my company, Solar, since we undertook the development of a 600-hp regenerative gas turbine to the same specification and in competition to the Orenda engine. This program was terminated early by the Army and Navy before a complete engine could be tested. I feel especially qualified to testify to the size of the task undertaken by Orenda in developing this 600-hp turbine as outlined by Mr. Quan.

The Army and Navy specification called for extremely difficult requirements. One of the most difficult overall requirements ever written for a gas turbine with the exception of the most recent specification for a 1500-hp turbine to replace the 600-hp turbine.

The attainment of 34 percent thermal efficiency, as required by the specification, has been achieved only by a few large central power station type gas turbines in Europe. In addition to large size, these central power units have had the advantage of almost unlimited space and weight to work with. As a comparison, the 34 percent thermal efficiency objective of the 600-hp OT-4 engine is to be obtained in a volume of 50 cu ft and a weight of 1500 lb.

It has long been apparent that the key to high efficiency mobile gas turbines is the development of a compact, high output heat exchanger. The choice is limited to two types—the stationary recuperator and the rotary regenerator, both of which have their advantages and disadvantages—but more important are the difficult engineering problems associated with both types in mobile applications.

Orenda's selection of the stationary recuperator is in contrast to other companies who have chosen the rotary regenerator for their vehicular gas turbines. Orenda appears to have made good progress with the recuperator and further progress will be watched with considerable interest.

One of the potential problems often cited against a recuperator is that of fouling. With the rotary type, experience has shown that fouling is much less critical. Would Mr. Quan comment on fouling experience to date on the OT-4 recuperator?

It is noted that growth potential projected for the OT-4 is about 75 percent over the present 600-hp rating or 1050 hp, and Mr. Quan reports that this can be attained without a significant increase in engine volume. Would Mr. Quan comment on how this is to be accomplished without greatly increasing internal aerodynamic losses, usually the Achilles heel in recuperative turbine uprating?

The achievement of the Orenda engine, as outlined by Mr. Quan, even though somewhat short of the ultimate target at this stage of development, is nevertheless significant. If requirements of the specification can be met, the gas turbine will be well on its way to competing head-on with the diesel engine.

H. J. Wood

It is a privilege to have an opportunity to discuss Mr. Quan's very interesting paper which describes one of the most important automotive gas turbine projects currently active. It must have a strong influence on the introduction of gas turbine engines into industrial and military vehicles, since it seeks to match piston engine performance.

In examining the statistics presented, I was struck by the relatively small through-flow for the size of turbomachinery. This can conveniently be expressed by a parameter consisting of the through-flow multiplied by the square of the rpm. The value of this parameter for this engine is such as to suggest that it would be unusually sensitive to bearing friction and tip clearances. This seems to be indicated by development experience to date. The indication is that the through-flow could be doubled without significantly increasing engine size (except for the recuperators), and this should result in lower relative mechanical losses and higher flow path efficiency. I mention this point since it is often regarded as conservative to hold the rotative speed down, but this conservatism has serious penalties in terms of cost, flow path efficiency, and mechanical losses.

It is not clear from the paper as to whether the power turbine is supported by a single bearing and the centering action of a planet pinion. If so, this is a very interesting construction and some information on its stability would be helpful.

As the paper was prepared in May, 1965, the author undoubtedly will have obtained much new data since then. An curve of part-load characteristics would be a valuable addition to the paper. Of particular interest would be an indication of the ratio of idling fuel flow to that at maximum power. So far, the diesel seems unbeatable for load profiles which require a lot of idling time.

Author's Closure

In reply to Mr. Pitt:

(a) Fouling of heat exchangers: During early engine testing, considerable fouling of the heat exchangers was experienced with engines which leaked oil. Fouling of heat exchangers is not a problem with good combustion and no oil leaks.

(b) Internal aerodynamic losses: The 1050-hp growth version of the OT-4 is based on increasing the engine airflow and turbine inlet temperature. The maximum packaging potential of the present engine has not been fully exploited. Increases in the critical internal ducts and frontal area of the heat exchanger can be accomplished with a nominal increase in engine volume.

In reply to Mr. Wood:

(a) Power turbine support: The power turbine is supported by a single bearing and is dependent upon the centering action of

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2 Vice-president, engineering and research, Solar Division, International Harvester Company, San Diego, Calif. Mem. ASME.
For the primary propulsion system, are the gear ratios one to one? It is realized, of course, that the vessel being described is really a hydrofoil and the gas turbine. It is therefore unfortunate that the performance characteristics of the hydrofoil craft.

While the hydrofoil development continued to stall. However, the transmission system and gas turbines, it was confidently expected that these two programs would progress together. Subsequently, other factors tended to impede the hydrofoil program so that the gas turbine went on to full development and acceptance in aircraft propulsion while the hydrofoil development continued to stall. However, the hydrofoil vessel larger than 50 tons was not inerably tied to the gas turbine, as the paper seems to indicate, since the German Navy successfully built and tested a 80-ton hydrofoil tank transport, the V88, during World War II. Nevertheless, it can't be argued that the gas turbine can significantly enhance the performance characteristics of the hydrofoil craft.

The vessel described in this paper represents one of the most significant examples in the world today of the combination of the hydrofoil and the gas turbine. It is therefore unfortunate that the paper does not contain more information. The paper leaves unanswered nearly as many questions as are answered, especially in the area of philosophy of design and expected performance. It is realized, of course, that the vessel being described is really a warship and as such must retain some areas of secrecy to be effective. And, of course, the engineering and scientific community is grateful for the information which has been published to date. But perhaps the authors can give some additional particulars of great interest without revealing sensitive information.

For instance, the Pratt & Whitney FT4A-3 gas turbine is rated at 30,000 hp maximum intermittent at sea level and 80 deg F for hydrofoil application. Are the transmission system and propeller designed to absorb this much power? If not, what is the maximum power designed into the propulsion system? For the primary propulsion system, are the gear ratios one to one for the inboard and outboard gear boxes? If not, what is the designed propeller rpm at the 22,000 shp? What is the expected takeoff horsepower requirement in smooth water?

The paper indicates both a high pressure and a low pressure air start capability for the main engine with the high pressure air source in bottles and the low pressure capability furnished from the emergency gas turbine. It is not clear from the engine room layout of Fig. 4 whether there is an air compressor for recharging the high pressure air bottles. Are they rechargeable from within the vessel? If not, could the authors reveal how many high pressure air starts are provided? For motoring the engine to achieve rapid cooling preparatory to water-washing, can either high pressure or low pressure air be used?

The foregoing questions represent the type of additional general information which would be of great interest. Also, a subsequent paper is anticipated in 18 months reporting on the actual performance encountered by the main and auxiliary engines, the transmission systems, and the propellers would be of tremendous value.

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Gas Turbine Engines in the Royal Canadian Navy Prototype Hydrofoil Vessel

R. E. Apple

As this paper has indicated, the use of gas turbines for the propulsion of hydrofoil craft has long been recognized as the most obvious and natural marine application for this type of power plant. During the early stages of the development of hydrofoils and gas turbines, it was confidently expected that these two programs would progress together. Subsequently, other factors tended to impede the hydrofoil program so that the gas turbine went on to full development and acceptance in aircraft propulsion while the hydrofoil development continued to stall. However, the hydrofoil vessel larger than 50 tons was not inexorably tied to the gas turbine, as the paper seems to indicate, since the German Navy successfully built and tested a 80-ton hydrofoil tank transport, the V88, during World War II. Nevertheless, it can't be argued that the gas turbine can significantly enhance the performance characteristics of the hydrofoil craft.

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K. A. Austin

The need for ASW vessels capable of both extended range and high combat speed is generally acknowledged. The Royal Canadian Navy is therefore to be congratulated on carrying their consistent interest in hydrofoil craft through to the stage of building a prototype vessel of adequate operational size. This concept and the forthcoming trials will certainly be a significant influence on future fast ASW designs.

Considering the vessel propulsion system, I would be pleased to hear comments on the following two points:

1. **Environment Control.** During foilborne operation the turbine air intake is some 30 ft above mean water level. At this height, the majority of salt water particles are likely to be small enough (i.e., below 20 microns) to pass untouched through the intake splitters and hence into the engine. Has second-stage electrostatic filtration been considered to remove this contaminant?

2. **Foilborne Propulsion.** In light of recent interest in water jet propulsion, do the authors consider that the mechanically driven cavitation propeller system offers any particular engineering or operational advantage?

J. F. Dunne

As discussed in the opening description of the vehicle, this size of hydrofoil is practical only because of the existence of a high-powered, lightweight gas turbine engine. The practical design of any hydrofoil over 100 tons in displacement, capable of achieving speeds better than 40 knots in unprotected waters (state five seas or greater) is absolutely dependent on the use of lightweight, marinized aircraft-type, high-powered gas turbines. The basic engine, the Pratt & Whitney FT-4A, was actually developed as a marine version of the J75 jet engine under the U. S. Navy Hydrofoil Accelerated Research Program. (Operation in the FH4 400 should disclose the adequacy of the engine for all future hydrofoil service, although undoubtedly it will prove to be more reliable than the rest of the main propulsion system.) Besides hydrofoil vehicles, the future development of large surface effect ships or hovercraft is quite definitely limited to the use of marinized aircraft turbojets, as well may be the case for practically all future large, high speed ships.

In the hullborne mode of operation, do the overrunning clutches in the main transmission system allow for windmilling of the main propellers without turning the propulsion engine power turbine, or is provision made for lubrication of the engine under this condition?

Recognizing that this paper deals mainly with the prime movers, would the authors have any information with regard to the supercavitating propeller designs? In particular, was a wake analysis of the propulsion nacelles conducted, and was the number of propeller blades based on the harmonic analysis of that survey, and of what material will these propellers be manufactured?

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