A MARINE INSTALLATION OF THE ALLISON 570KF
FIRST PHASE

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ABSTRACT
With the obsolescence of the original cruise engine of the Canadian Navy DDH 280 Class Destroyers, it became necessary to find and fit a new cruise engine. The Allison 570KF engine was selected and installed during the half life refit and modernisation of the ship class. In addition to the engine replacement there were many changes to the support equipment which have had a large influence on the new installation.

This paper describes the first phase of the set to work and trials of the new installation and the difficulties encountered. Two ships are now at sea and undergoing extensive system trials as they carry out their Naval duties.

INTRODUCTION
In 1972 Canada added the DDH 280 Class of anti-submarine Destroyers to its Naval Fleet. These ships used gas turbine engines for the propulsive power and as prime movers for electric generation. After about 15 years of very satisfactory service, a project to update the ships was started and included the fitment of new engines to replace the obsolete propulsion cruise power units.

This paper will briefly state the rationale for the new cruise engine selection and describe some early problems encountered in the set-to-work process. Although the particular problems relate to the Canadian Navy installation, it is held that they are generally typical of the problems being faced in installations using today's standard of technical development. Two of the four ships of Class have now been returned to Naval service and are undergoing trials of the new engines together with the large array of other equipment. A number of difficulties have arisen regarding the operation of the engines in the course of these trials which it is now considered opportune to report.

THE NEW CRUISE ENGINE
The design of the DDH 280 Class was hailed as a great advance into marine gas turbine power when built in the early 1970's with a Combined Gas Or Gas (COGOG) machinery arrangement. The use of two propellers each driven by a Pratt & Whitney FT4 of 25000 hp for high speed operation or a Pratt & Whitney FT12 of 3400 hp for long range cruising, has proven to be a good combination. However, the cruising speed available from the FT12 was below that required for many naval operations so that the FT4 was used for more than half of the total operating time. Of course, the efficiency of the large FT4 is poor at under 20% of its maximum continuous power rating and it was apparent that a major fuel saving would result from an increase of cruise power.

Although there had been hopes that the FT12 would be up-rated, this had not happened and neither had it achieved high popularity in the market place. It was therefore soon to become obsolete and, by the mid 1980's, a new cruise engine had to be found for the DDH 280 Class. Analysis of the actual ship operating profile showed that the optimum power for the cruise engine to deliver to the propeller was around 5500 hp (4100 kW). This would reduce substantially the usage of the FT4 and accrue savings of fuel and maintenance costs. The fuel saving would be enhanced further if the improved efficiency offered by a modern plant was also employed. These factors plus the anticipated diminishing industrial support base available for the FT12 formed the argument to justify the acquisition of a new plant with a pay back in about 10 years.

Several engines available at that time were studied as candidates but the required power rating narrowed the field to a new engine being marketed by the Allison Company as the Allison 570K. This engine was derived from the T701 engine which had been developed for use in the US Army Heavy Lift Helicopter programme. This programme was cancelled before the first flight and the Allison Company converted the T701 engine for industrial and marine applications with the designation 570K. To meet the...
requirements of the Canadian Navy, the liquid fuel version of the engine (570KF) was specified with the intent of operating on diesel #2 fuel. Tests of the engine showed a higher than acceptable smoke emission and Allison undertook to alter the combustion chamber design to bring smoke levels within the required specification. In another trial, this time sponsored by the Canadian Government, Allison investigated the starting characteristics of the "smokeless" engine over a wide range of ambient temperatures with the purpose of proving the starting characteristics and of defining the control algorithms for the start process. The engines supplied to the Canadian Navy, although similar to the previous 570KF genre, were therefore unique.

THE INSTALLATION

The original pair of Pratt & Whitney FT12 cruise engines were designed with axial intakes, hot end drive and handed power turbines. Consequently, the engine room was arranged with the intake ducting forward and the exhaust trunks and drive lines aft. The new Allison 570KF engines replacing the FT12's in the same location have radial intakes, cold end drive and uni-directional power turbines. Thus the new installation has required a radical change to the engine room layout and the addition of speed and direction matching gearboxes. Other parts of the ship update program affecting the cruise engine arrangement have been:

a. the addition of an Integrated Machinery Control System to which the new engine, with its own electronic controller has had to be integrated;

b. an upgrading of the hydraulic starting package to reduce hydraulic hammer in the high pressure system;

c. increased power transmission through the cruise reduction gear train in the main reduction gearbox;

d. the introduction of an infra-red suppression system to the uptakes, with an attendant increase in back pressure to the engine; and

e. the requirement for heated fuel and the incorporation in the ship of a water displaced fuel system with the attendant suspicion of water contamination.

It can be seen that a fertile ground for problems exists in these systems within the engine environment. It is a credit to the system designers that operation is possible at this time but the problems are far from complete resolution.

STARTING PROBLEMS

On the first trials period in HMCS ALGONQUIN, in mid 1991 there were rumours of flames emanating from the ship funnels during starting of the Allison engines. Before this could be investigated, an unrelated incident caused one engine to be flooded with sea water after which it was removed and inspected. At this inspection, serious burning damage to the second stage turbine nozzles was discovered. When the replacement engine was ready for trial, observations of the exhaust were made and large luminous flames were seen for many seconds during what appeared to be a "normal" start. Subsequent trials with Allison staff in attendance and with extra instrumentation applied to the engine showed that the Quick Fill Valve (QFV) which temporarily opens a bypass around the Fuel Metering Valve prior to ignition was delayed in closing and so was open during the whole start sequence and allowed the total output of the fuel pump to enter the engine. The cause was not positively identified but was probably due to a logic fault in the control system. The extra instrumentation showed that the massive over fuelling produced a cooler than normal start with combustion occurring throughout the turbine and exhaust system and for perhaps twenty feet above the funnel. Correction of the QFV sequence by hard wiring to the fuel manifold pressure switch rather than using computerised switching resolved this problem but it was a harbinger of more serious difficulties in the engine starting process. The instrumentation gave clues to a number of anomalies in the start process and a revised set of instrumentation was devised to explore further.

Trials of the start process undertaken jointly by Canadian National Defence and Allison on a Canadian engine at the National Airmotive Corporation overhaul facility revealed some interesting results with respect to the effect of a compressor geometry change and alteration of the fuel flow schedule. Flow was varied over a wide range and a schedule was established which gave repeatable satisfactory starts at ambient conditions close to Standard Day (15 -20°C). The same settings were used in the two engines of HMCS Algonquin at Halifax with ambient temperature in the -5 to 0°C range. Here, there were several stalled starts until a new fuel schedule was set by Allison personnel and again satisfactory starting was achieved provided that the engine had been allowed to cool since the last start attempt.

It now is clear that the engine is particularly sensitive to variations of the start process, particularly to the fuel admission sequence, to the residual temperature in the combustor section, of compressor vane setting and of starter operation. If even minor variation occur in these critical items, the engine is likely to encounter excessive temperatures through the turbine system. This sensitivity is such that specialist staff have been required to be present at most start attempts and fine adjustment of the control setting is necessary before repeatable successful starts are achieved. The concern for the start process is not ameliorated by the statement in the Allison report of trials, sponsored by the Department into cold weather starting where it was concluded that more development was necessary before reliable starting could be ensured. Attempts have yet to be made to operate the engines over a substantial range of ambient temperatures without adjustment of the control system.

COMBUSTION PROBLEMS

The combustor of the Canadian version of the 570KF engine is of a special design to minimise smoke emissions. Shipboard trials have indicated that during the start process, the combustor is very close to weak limit extinction as although gas temperatures are high, a small reduction in the fuel schedule causes a rapid reduction in temperature and a heavy discharge of white smoke. This feature has been employed to provide a lower gas temperature during a critical part of the start, in fact successful starting appears to require at least one such incident during the...
of this problem but further investigation is required. Some proposal and sponsored by Allison and were the outcome of CVG vane angles and a reduction of the fuelling rate in the sub-region. These CVG setting and schedule changes were idle region. These CVG setting and schedule changes were considered to be significant at low secondary flows and might be expected to produce late burning. There is the suggestion that metallic or biological contamination of the fuel might be a cause of this problem but further investigation is required. Some improvement of the design of either the fuel nozzle system or the ship fuel system is seen to be necessary before long term reliable operation in the naval environment with diesel fuel is achieved.

**COMPRESSOR STALLS**

A persistent problem has been the tendency for stall conditions to occur in the compressor during the start. Many starts recorded have encountered some form of stall, presumably a rotating stall, at the first movement of the compressor variable geometry (CVG). In the stalled condition, there is a reduction in air flow with a corresponding reduction in the compressor delivery pressure and an increase in the gas temperature. This often leads to a stagnation condition where the engine speed remains at a sub-idle level with an elevated gas temperature until tripped. This situation has been improved by a revision to the setting of the CVG vane angles and a reduction of the fuelling rate in the sub-idle region. These CVG setting and schedule changes were proposed and sponsored by Allison and were the outcome of an investigation into compressor blade stress. They are considered essential to avoid a severe negative impact on the engine life.

Traces have been made of compressor speed, compressor discharge pressure, inter turbine gas temperature, inlet pressure, compressor variable geometry position and fuel manifold pressure during both successful and a stagnated starts. The effect of compressor stall is clearly seen by the oscillating discharge pressure and the pulsating inlet pressure. Roughness in the trace of compressor discharge pressure prior to the vane position change is believed to be indicative of aerodynamic instability if not actual stall conditions.

Attempts to re-start the engine soon after a shut down, when a high residual temperature remains in the combustor section have consistently resulted in stalls and stagnated starts. It is postulated that this is caused by a lowering of the weak limit of combustion which prevents the partial extinction during the start and allows the rapid temperature and therefore pressure rise to occur in the critical stall region. Tests of the new settings for the CVG and fuelling rate, at the National Airmotive Corporation trials showed a complete absence of the stalls but, although the recent recordings of ship installations do show an improvement, the complete elimination of stagnated starts under all ambient conditions has yet to be confirmed. Further work is required to develop a starting algorithm that gives consistent starts in all normal operating conditions without running the risk of the serious damage implied by this stall phenomenon.

**ELECTRICAL GROUND FAULTS**

The interfacing of the Allison/Bendix analogue electronic engine control system with the ship's new digital integrated machinery control system has proved to be a problem. Different grounding techniques employed in the two systems coupled with wiring errors appear to have caused a variety of noise and signal level difficulties. In some instances these appear to have upset the system logic and prevented proper operation of control functions. In other cases, the high noise levels have produced errors in CVG position feedback and possibly in the Fuel Metering Valve positioning. A related problem arose due to the requirement to start the engine with a stationary propeller and therefore power turbine. The static friction of the long and heavy shaft line requires a substantial torque to start rotation and this in turn requires the gas generator section to accelerate and produce significant gas horsepower. However, the torque meter output which relies on a rotating power turbine shaft to enable proper measurement is confused at zero speed and randomly produces an over torque signal which prevents raising the gas generator power above idle. Hence the gas producer speed may become locked at idle and no rotation of the power turbine is possible. A manual over-ride of the over-torque signal has now been fitted to allow trials to continue but correction of the problem will require modification of the torque meter circuit.

**MECHANICAL PROBLEMS**

At the first opportunity to measure the vibration over the full power range, a high level of vibration at half of the fundamental frequency of the gas generator spool (½ N₁) was discovered. This mode of vibration is not normally present in gas turbine engines and on investigation it was found that the starter drive shaft rotates at close to this speed thus suggesting a misalignment of this shaft. Before completion of the vibration survey, a seal on one of the starter shafts developed a large oil leak and forced a shutdown. A re-alignment of the starter drive shaft is thought to have improved the immediate situation but high vibration levels persist at ½ N₁ and have since been observed on all four of the running installations. Another interesting vibration observation is that the power turbine shaft fundamental is generally high, appreciably higher than that of the gas producer spool. The significance, if any, of this is not understood but investigation of hot condition alignment of the power output shaft is suggested.
Vibration at the fundamental frequency of the gas producer spool often passes through a high level at intermediate powers. On one occasion this proved to be the result of incorrect seating of a main shaft bearing during assembly but the frequency of this phenomenon gives cause for some concern. Vibration signature knowledge of this engine is only at an early stage of exploration at present and much work is needed to be done before a clear picture can emerge.

The lube oil system employed on this installation has a high tank level which brings the potential for flooding when the engine is stationary. To overcome this possibility, a valve is placed in the supply pipe to the engine. This is not a recommended practice and already there has been one close call when the valve closed erroneously during running.

EXHAUST TRUNKING
To accommodate the tight space limitations of the engine room, the axial exhaust of the engine is taken into a plenum and allowed to exit radially. A rectangular duct then carries the gases inboard to the uptake space and thence up to the ship funnel. Several problems have occurred with this assembly. The first was a rippling of the conical section just downstream of the engine, probably caused by excessive temperatures suffered in hot starts. The next problem was the failure of a number of retaining bolts holding the end cover on the plenum. The cover fell away and allowed high temperature gases to blow on to other equipment with some damage. The failure of the securing bolts was attributed to the use of zinc plating on the bolts which at high temperature causes embrittlement of the steel. The latest failure in this area was the partial disintegration and burning of an expansion joint. Here the over zealous application of lagging is thought to have caused the soft elastomeric outer covering to become over heated. Temperature measurements will be made in this area when the repaired joint is returned to service.

THE WAY AHEAD
Good performance at high power has been demonstrated by the new engines which has been found to be generally in accordance with the manufacturers specifications. There is therefore high confidence that the engine has a bright future in the Canadian Navy but as can be seen from the tone of this paper, the cruise engine installation still has a number of difficulties to be overcome before the new arrangement is ready for normal Naval duties. To reduce the interference of testing work aboard the ships, a test cell at the Naval Engineering Test Establishment (NETE) in Montreal is being prepared for the Allison 570KF. The immediate test program is to employ an elementary test stand to explore the starting regime and attempt to demonstrate engine starting in all weather conditions. As more equipment becomes available, the scope of testing will be expanded to include full power operation using a dynamometer and a closer simulation of the ship installation including intake and exhaust trunks. The work is planned to be conducted in cooperation with the Allison Company with whom there is a good technical rapport. There is therefore every confidence that with appropriate attention to the troublesome details encountered, the installation will deliver the benefits originally promised.
CRUISE ENGINE INSTALLATION - PORT SIDE

INFRA-RED SUPPRESSORS

INTEGRATED MACHINERY CONTROL SYSTEM CONSOLES

LOCAL OPERATION PANEL

REDUCTION GEAR BOX

CRUISE ENGINE INTAKE DEMISTER AND DUCT

CRUISE ENGINE REDUCTION GEAR BOX

MAIN ENGINE

REMOTE TERMINAL UNIT

EXHAUST DUCT

INTAKE DUCT

ENGINE ENCLOSURE

SPEED AND DIRECTION MATCHING GEAR BOX

ELEMENTS OF THE PROPULSION SYSTEM