Gem Cyclic Life Control: A Smarter Maintenance Item within the Royal Netherlands Navy

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Abstract

As part of a general Smarter Maintenance policy, the Royal Netherlands Navy has implemented the so-called Cyclic Life Control concept for the engines of its Westland Lynx helicopters. The aim is to have an autonomous, cost-effective and simple way to decrease costs on hard time maintenance.
Cyclic Life Control allows the Royal Netherlands Navy to benefit from helicopter engine usage severity that is considerably lighter than is being assumed by the engine manufacturer, i.e. assumed exchange rates turn out to be conservative by a factor of up to 2.
This paper shortly addresses some major topics within the current Royal Netherlands Navy maintenance policy and describes the newly adopted Cyclic Life Control concept in more detail. The paper focuses on the operator's view on system implementation and cost benefit analysis, and illustrates how a relatively small operator greatly benefits from an individual maintenance policy.

Introduction

In The Netherlands the international political developments of the last decade coincided with rather drastic changes within the national defence organisation. The Air Force is building an Air Mobile Brigade and operates the largest number of different aircraft types ever, the Army is transferring to being all-professional and the Fleet Air Arm of the Royal Netherlands Navy (RNLN) sees its role quickly expanding into new environmental, UN peacekeeping, coastguard and drug enforcement tasks. For economical reasons, all these changes will have to take effect under budget as well as personnel restraints.

With its fleet of 13 maritime patrol Orion aircraft and 22 Westland Lynx helicopters, one of the RNLN targets is Smarter Maintenance, i.e. achieving more economy with less financial or manhour effort, meanwhile maintaining a high safety standard.

The RNLN Lynx helicopter

The RNLN operates a fleet of 22 Westland Lynx helicopters since 1976 from Naval Air Station De Kooy, a coastal location in the north of Holland. The maritime twin-engine multi-role Lynx helicopter is used within the RNLN for a variety of ship- and ground-based roles such as:
* Anti Sub-surface Warfare
* Anti Surface Warfare
* Sonar Dunking
* Boarding
* Transport
* Counter Drugs Operations
* Search and Rescue
* Coastguard tasks, e.g. environmental control

Projected operational demand lies at appr. 7000 flighthours for the entire Lynx fleet, i.e. appr. 300 to 350 flighthours per year per helicopter. This high degree of utilization has caused the RNLN to be one of the leading operators of the Lynx when it comes to fatigue life consumption.
Consequently, the RNLN has always felt the need to increase its knowledge on Lynx usage or, more specifically, to gain more insight into fatigue loading characteristics of its airframe, rotor system and engines. As an independent research organisation, the National Aerospace Laboratory NLR proves to be significant in a supportive role.

Each Lynx is equipped with two three-spool Rolls-Royce Gem gas turbines of modular design, see figure 1. Engine maintenance procedures are a mixture of 'on-condition' and 'safe-life' with prescribed periodic checks concerning performance trends, oil consumption, SOAP and debris analyses and cracking of engine parts, and with finite (hard time) lives for the rotative parts.

Smarter Maintenance

As indicated above, the RNLN had to reconsider its maintenance policy to cope with a changing and more demanding operational environment. Since engine maintenance generally represents a large percentage of overall maintenance costs (appr. 30%) much attention was payed to engine topics. A few results of this change in maintenance policy are presented on the next page.

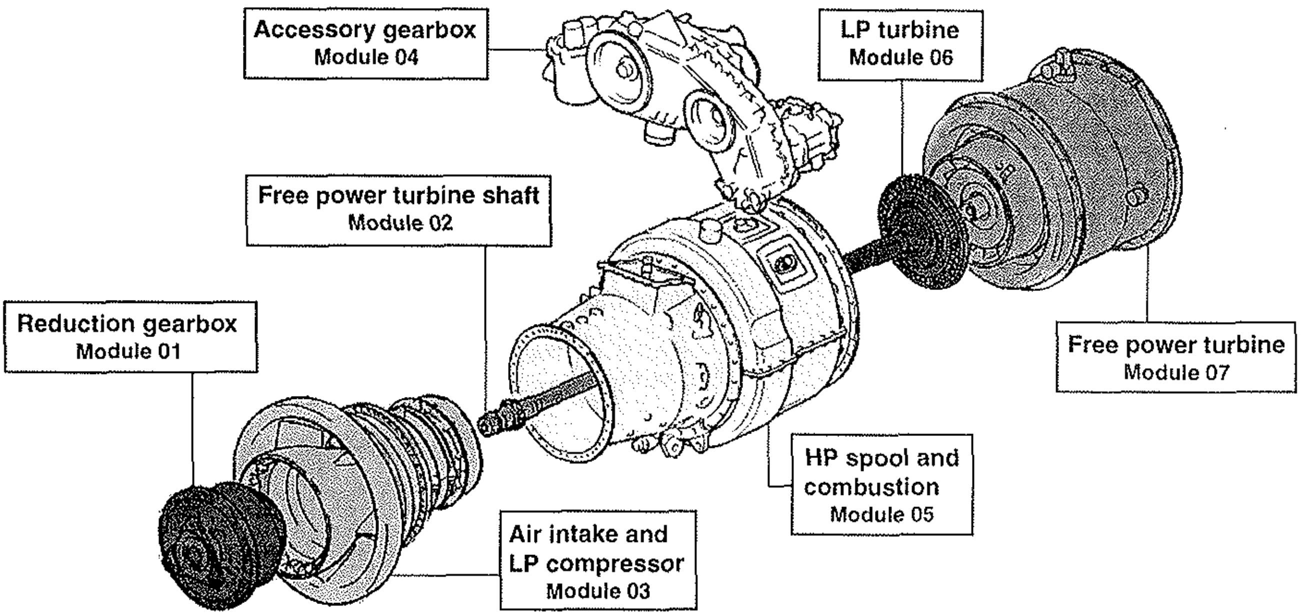

Fig. 1 The modular Gem engine

Engine conversion

Originally, three versions of the Lynx helicopter existed in the RNLN depending on its operational role, i.e. the UH-14A equipped with Gem2 engines for transport, the UH-14B equipped with Gem4 engines for ship-based sonar operations and the UH-14C, also with the Gem4 engine, for ASW-missions.

It was considered cost-effective by the RNLN to modify the three different helicopter versions to one version, the SH-14D helicopter. Apart from the benefit of having one airframe configuration, only, this also gave the opportunity to convert the two different Gem engine types to one standard, the more modern and more reliable Gem42.

Rolls-Royce claimed that an investment in this conversion would increase MTBR from 250 flighthours (for Gem2) or 350 flighthours (for Gem4) to about 1000 flighthours for the Gem42 engine. The conversion program comprised a redesign of combustion chamber, turbine nozzle, compressor air inlet housing and some 115(!) additional smaller modifications that would increase engine reliability.

The engine conversion programme was conducted under a contract with Rolls-Royce in which the above potential benefits were guaranteed against a penalty for not meeting the targets set. To date appr. 70,000 Gem42 operating hours have been accumulated and it turns out that the promised increase in reliability has been reached, yielding about $2.5 million of costs savings on a yearly basis. The break-even point of the necessary investments, associated with the engine standardisation programme, is expected to be reached in 1997.

Parts repair during overhaul

60% of engine maintenance costs is due to replacement of parts that are degraded beyond limits. Although favourable because of short turn-around times, 'repair by replacement' is not cost-effective for the operator.

This has led to a RNLN policy to task contractors to develop new repair methods for high value non-repairable parts, and to act as an negotiator for the contractors in their effort to receive formal authorization from the engine manufacturer for the repair.

This new maintenance policy has proven to be very cost-effective, and has initiated that some major components are now being weld-repaired instead of exchanged for new. For the gas generator module of the Gem engine, for example, costs for a complete overhaul are lowered with appr. 25%.

Use of modern coatings

Engine parts with high rejection rates during maintenance are evaluated for possible protection with modern coatings. The RNLN tasked development of new engine coating applications and greatly benefits from this investment. For example, Allison T56 compressors of the Orion aircraft are coated with a modern coating improving compressor MTBR from 2500 to 4000 flighthours. Estimated savings for the RNLN are appr. $0.6 million on a yearly basis.

Cost savings related to hard time maintenance

Looking at potential cost savings with respect to hard time lifed rotative parts of the Gem engine, the RNLN was triggered by a Rolls-Royce Service Bulletin in which the operator is offered the opportunity to track engine usage (i.e. fatigue life consumption) in terms of cycles instead of hours. Funded by the RNLN, the NLR developed a simple autonomous on-board data-acquisition system to monitor engine usage during flight. The measurement data is used to derive tailored engine module exchange rates for the RNLN. This topic is the main subject of this paper and will be worked out below.

Cyclic Life Control

Lifing method

Traditional engine component lifing methodology is based on the Safe Life principle, which is two-fold. On the one hand, the component material's fatigue resistance to low cycle fatigue loading cycles must be determined by means of laboratory testing. The safe life derived from these tests is defined as the number of start/stop or zero-max-zero *cycles* at which, say, in 1 of every 1000 components a crack grows to a certain size, see left side of figure 2. On the other hand, see right side of figure 2, the character and severity of service loading (the usage spectrum) must be known to the manufacturer in order to estimate the amount of cycle consumption per flighthour. By combining left and right side of figure 2, a safe life or retirement life in flying hours is found after which the component needs to be removed from service, regardless of the presence of a crack.

But breaking down a given usage spectrum in terms of cycles poses a problem. Under operational circumstances an engine component does not only experience zero-max-zero loading cycles, but it will be operated in a far more complex way. In-service loading is a mixture of *major cycles* associated with starting-up and shutting-down of the engine and *minor cycles* associated with in-flight events leading to throttle movements.

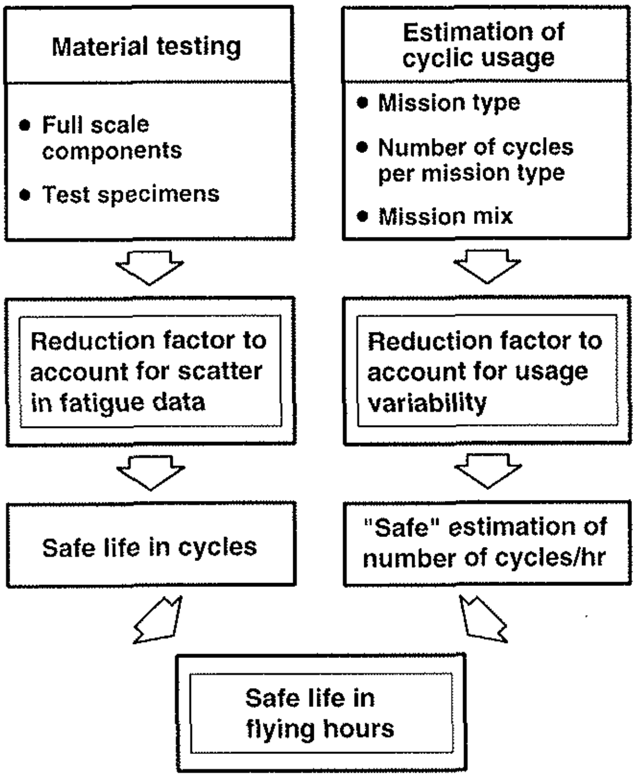

Fig. 2 Safe-life calculation procedure

Consequently, when calculating fatigue damage from a given load spectrum there is a need to express minor cycles within the spectrum in terms of these major zero-max-zero cycles, i.e. to give each minor cycle a 'damage-severity value' relative to the zero-max-zero cycle.

Traditionally, this is done by the manufacturer during the engine design phase by deriving a so-called *exchange rate*. This exchange rate specifies fatigue damage by estimating the total (major plus converted minor) number of cycles for each of the anticipated mission types and by estimating the length of each of these mission types. This yields a direct relation between flighttime in hours and fatigue damage. In order to guarantee that 'severe' operators will not operate unsafe compared to 'mild' operators, a certain level of conservatism will be built in, i.e. an exchange-rate applying to the most severe anticipated future usage will be incorporated in the design.

Usage monitoring

In recent years, instead of applying an assumed overall 'too severe' exchange rate (i.e. calculated cycles per hour), usage monitoring procedures are evolving to provide a better understanding of actual service loading. This eliminates part of the design uncertainties mentioned above, giving rise to less severe reduction factors in the retirement life specifications. This may also mean upgrading to longer retirement lives if expressed in engine cycles and, thus, cost savings.

Additionally, usage monitoring may be used as a management tool if it indicates major damaging events within the operator's usage. By using this kind of information the operator can change logistic-, flight- or maintenance-procedures to allow a more economical helicopter usage.

The Cyclic Life Control concept

Such an engine usage monitoring concept has been worked out by Rolls-Royce for the Gem engine. For more than ten years, Lynx operators are being provided with a Service Bulletin subjected to application of the so-called Cyclic Life Control concept for GEM engines [1]. The Service Bulletin not only specifies component and engine module retirement lives or TBO's (Time-Between-Overhauls) in *flying hours* but also in terms of actually flown and factored engine *cycles*, provided adequate in-flight cycle counting procedures are used.

The Service Bulletin also prescribes how to identify the cyclic content of each mission by continuously monitoring speed variations of the related engine components and how to derive the cycles from such a load-time history. This applies to zero-max-zero cycles, but also to partial cycles within the major ones. In the Service Bulletin severity- or weighting-factors are given for all possible cycle sizes of varying amplitude and varying mean level. By multiplying the measured cyclic content (i.e. the number and size of speed variations) with these severity factors, the damage can be expressed as 'cycles per hour' (exchange rate).

The operator view

The task of the *maintainer* is to ensure safe helicopter operations for the lowest possible costs. However, Smarter Maintenance procedures are never allowed to conflict with the task of the military *operator* to perform the demanded roles. Costs to the maintainer to ensure safe operations are no great issue for the operator, either.

This dilemma leaves little room for the maintainer to task operational crew with additional workload. For example, to manually record extra flight administration sheets or to manually operate an on-board data-acquisition system. Especially in military helicopter operations, improved maintenance tools need to be automatic and autonomous. Automatic means that existing flight crew procedures are not influenced, autonomous means that no further maintenance actions are required. The only allowed necessary crew action is downloading of the measurement data on a periodical basis.

Traditionally, newly developed usage monitoring procedures show considerable lead times and investments before they become effective, especially if an operator like the RNLN has to work by itself. If enhanced usage monitoring is to be successful, a potential data-acquisition system must be simple (positive effect on development time, acquisition costs and post-processing), user-friendly (positive effect on downloading) and easy to maintain (positive effect on maintenance manhours).

RNLN/NLR program

Although Rolls-Royce specifies component retirement lives in terms of cycles and also prescribes how to calculate cycle severity, no adequate cycle monitoring procedures were provided to the operators.
Rolls-Royce published an option which tasks the flightcrew to continuously monitor major and minor rotational speed variations during flight and to record them manually on special sheets, afterwards. Such a procedure is considered not-feasible from a technical point of view, but also opposes the military operator's general view on the usage monitoring burden, as set out earlier.

The lack of a useful engine monitoring system has led to a RNLN funded research project for the National Aerospace Laboratory NLR. Goal of this project was to develop a simple, cost-effective, reliable, user-friendly, easy to maintain, automatical and autonomous Gem engine monitoring system to record rotational speed variations of the gas generator (module 05) and the free power turbine (module 07). NLR designed, in conjunction with the German avionics company Swift, the cycle counter shown in figure 3, which has been in use successfully for several years within the RNLN by now.

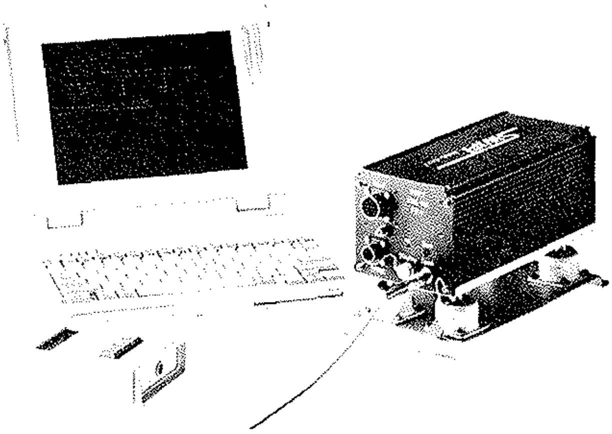
Fig. 3 The RNLN/NLR cycle counter

Fleetwide RNLN Cyclic Life Control (CLC) is based on four of these on-board cycle counters, which are operated on a sample-monitoring basis throughout the RNLN fleet of 22 Lynx helicopters [2-4]. Since Gem CLC is fully based on rotational speed variations of two engine modules, the cycle counter is capable of in-flight data acquisition and processing of four different tacho-generator signals. Upon each flight, four load-time histories are stored in condensed format in solid state memory, together with the total accumulated damage stemming from that flight. Periodically, but typically once per month, each cycle counter memory content is downloaded to diskette. This information is then sent to the NLR for off-line processing, i.e. to perform trend analyses, to derive tailored exchange rates and for reporting purposes.

A typical RPM-time history of Gem Gas Generator rotational speed is shown in figure 4, indicating how the various Lynx flight events generate changes in rotational speed. The cycle counter monitors four of these signals and applies a data reduction algorithm, before storage into memory and damage calculation.
Final results of RNLN CLC are shown in figure 5, comparing Rolls-Royce prescribed Lynx Gem engine exchange rates with actually measured RNLN exchange rates. It is shown that RNLN usage of the Gem engine is approximately 33 % (for the Gas Generator) to 82 % (for the Free Power Turbine) less severe than Rolls-Royce prescribes if no CLC is applied by the operator. These values directly relate to longer on-aircraft times of the engine and modules.

Cost-benefit analysis

CLC may be valuable for various reasons. Recent years

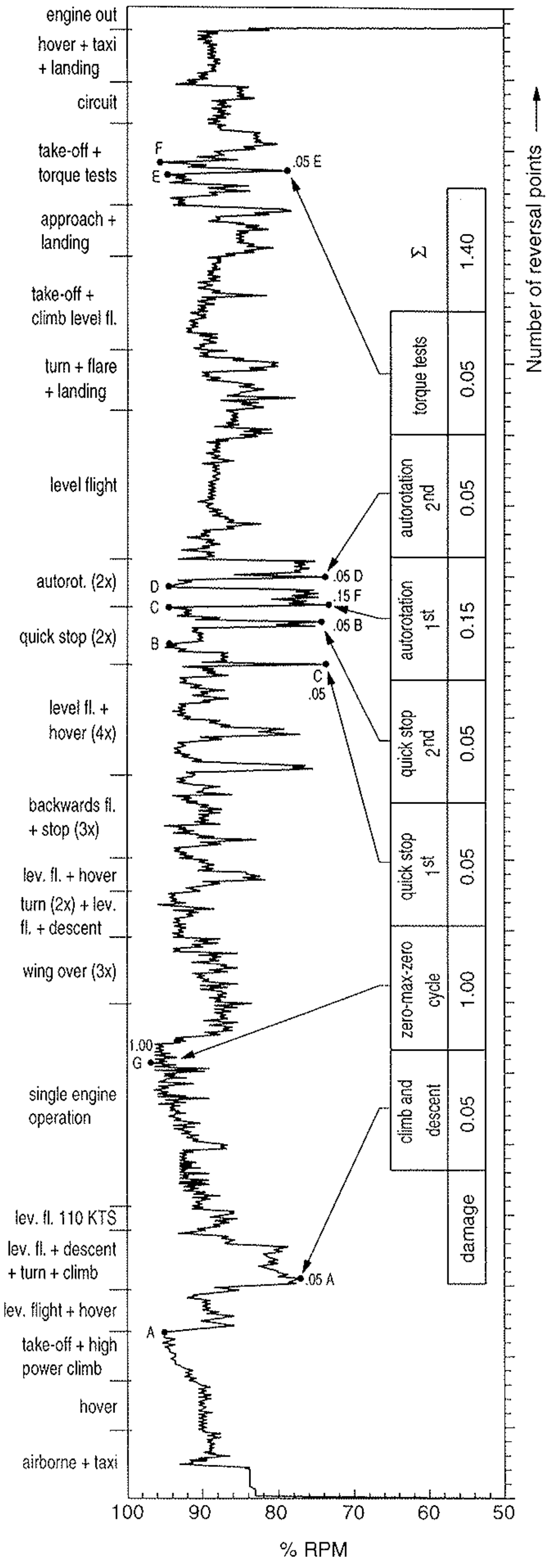

Fig. 4 RPM-time history of port-engine Gas Generator

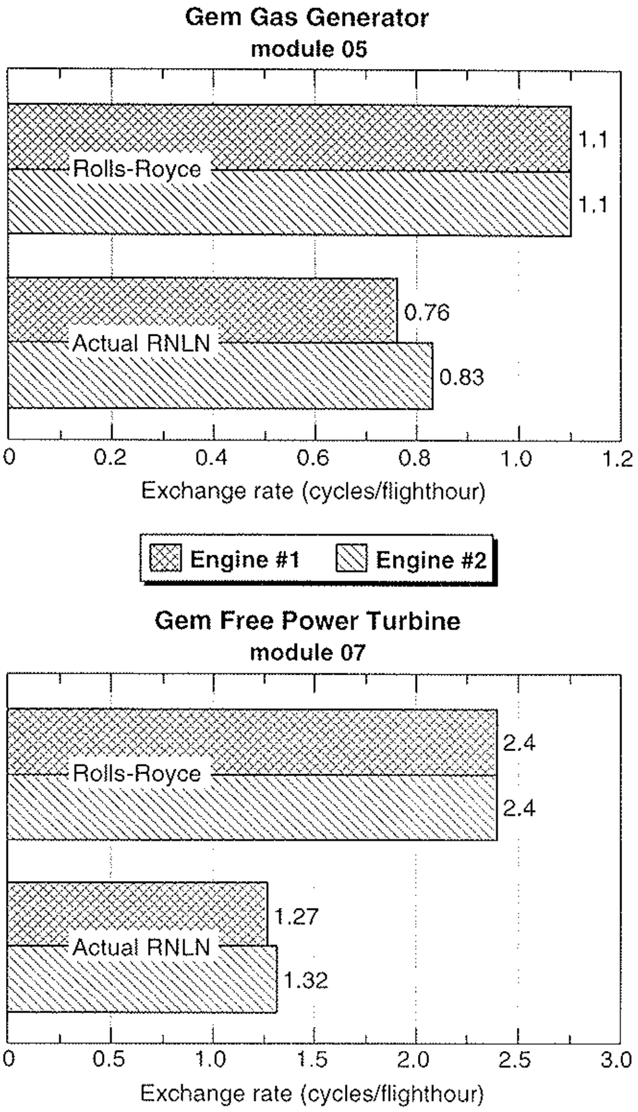

Fig. 5 Gem exchange rates for the Royal Netherlands Navy

have learned that the RNLN Lynx has to operate in a quickly changing environment with an increase in new tasks, e.g. 1991 Gulf War, UN missions, law enforcement, Caribbean deployment, etc. Being able to monitor engine usage, the RNLN can control and judge engine damage accumulation in this variety of roles. It makes the RNLN independent of any changes in Rolls-Royce issued exchange rate updates that have to be applied if no engine monitoring programme is active. This may yield cost savings.

Although the above potential benefit of usage monitoring may be obvious, it is often difficult to quantify the benefit in terms of 'dollars saved'. However, for the present RNLN Lynx engine cycle counter a direct cost-benefit analysis is shown below.

The RNLN plans to start operating with a new NH-90 helicopter type in year 2003. Until then the Lynx fleet must remain fully operational, which means, say, 8 to 10 more Lynx years to go from now (1996). If the numbers of necessary engine module overhauls are compared under the 'old' versus the 'new' regime (i.e. Rolls-Royce versus actual RNLN exchange rates), it turns out that:

- 50 % of all modules 07 (free power turbine) will need an overhaul if basic Rolls-Royce exchange rates are applied, while no single module 07 overhaul is needed if actual RNLN exchange rates are applied; total potential savings amount to about $2 million.
- 10% fewer modules 05 (gas generator) will need an overhaul if actual RNLN exchange rates are applied; total potential savings amount to about $1 million.

Cycle counter maintenance, downloading, NLR engineering support and reporting account to about $30,000 on a yearly basis, totalling to appr. $300,000 for the remaining Lynx operating time. Funds spent in the past on development, acquisition and installation totalled to appr. $400,000. Consequently, application of CLC has the potential to save the RNLN some $2,300,000 until the year 2003.

Concluding remarks

In this paper it is shown that the Royal Netherlands Navy greatly benefits from an independent maintenance policy. If certain rules for simplicity, user-friendliness and compatibility with existing procedures apply, operation of newly developed usage monitoring systems lies well within the scope of the military operator.

Although it is understood that other operators may have reasons to be less independent, the RNLN encourages them to share the underlying ideas of the present paper. Possibly with the consequence that the RNLN will not remain the only operator in the world applying Gem engine Cyclic Life Control as a highly practical and beneficial maintenance tool.

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