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An Automatic In-flight Data Acquisition System for the RNLN Lynx Helicopter

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ABSTRACT
As part of a maintenance cost reduction policy, the Royal Netherlands Navy RNLN recently funded the development, acquisition, certification and the fleetwide installation of a unique multi-channel on-board data-acquisition system for its Lynx helicopter, called AIDA (Automatic In-flight Data Acquisition). This 17-channel AIDA-system will generate valuable RNLN Lynx usage and loads data on main rotor, engines and airframe, thus enabling the RNLN to optimise Lynx maintenance until the NH90 comes into full service and the Lynx fleet will be phased out.

Apart from a technical description of the AIDS-system, the present paper describes how a relatively small operator, such as the RNLN, performed the rather complex AIDA develpment programme by itself.

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Abstract

As part of a maintenance cost reduction policy, the Royal Netherlands Navy RNLN recently funded the development, acquisition, certification and fleetwide installation of a unique multi-channel on-board data-acquisition system for its Lynx helicopter, called AIDA (Automatic In-flight Data Acquisition). This 17-channel AIDA-system will generate valuable RNLN Lynx usage and loads data on main rotor, engines and airframe, thus enabling the RNLN to optimise Lynx maintenance until the NH90 comes into full service and the Lynx fleet will be phased out.

Apart from a technical description of the AIDA-system, the present paper describes how a relatively small operator, such as the RNLN, performed the rather complex AIDA development programme by itself.

Introduction

The Lynx helicopter, shown in figure 1, is in service within the RNLN since the late 70’s. Since the late 80’s, the Lynx has been subject to an ongoing effort by the RNLN to decrease it’s maintenance costs, and to extend it’s operational service life beyond the Lynx’ expected airframe durability life [1]. This has led to a need for improved Lynx usage data within the design (GKN Westland[1]) and the maintenance (RNLN/DNAEM[2]) authority.
In addition, an urgent need for accurate Lynx main rotor (Nr) monitoring exists related to a large maintenance effort due to a tie-bar crash incident, see furtheron.

1 GKN Westland Helicopter Limited is the Lynx manufacturer
2 RNLN/DNAEM: Royal Netherlands Navy Director Naval Aircraft Engineering and Maintenance

The above need for Lynx usage data has led to the present development of an on-board data acquisition system for RNLN Lynx, called AIDA (Automatic In-flight Data Acquisition System). Under stringent conditions regarding allowable weight and dimensions, this system is capable of signal recording and data processing and triggers a set of limit exceedance warnings and performs a variety of off-line analyses.

The present paper describes the various RNLN Lynx operational tasks, and how AIDA is expected to play a supportive role. AIDA functionalities and technicalities will be described, also covering off-line data processing and certification aspects.

Fig. 1 The RNLN Lynx helicopter

RNLN Fleet and Operations

The main objective of the Royal Netherlands Navy (RNLN) is the effective use of fighting power at sea against threats. For this purpose the RNLN operates frigates, submarines, mine warfare vessels, fixed wing maritime patrol aircraft and helicopters. The frigate based Lynx helicopter is used as a weapon platform for Anti Submarine Warfare (ASW) and Anti Surface Warfare (ASuW) tasks.
As many other navies, the RNLN is confronted with a tendency towards coastal (so-called brown water) operations as opposed to the ocean (so-called blue water) operations in the past. This tendency leads to more ASuW operations in which the shipborn helicopter plays a major role.
In order to better prepare the RNLN Lynx helicopter for these type of operations, a number of different systems is momentarily being installed, such as Radar Warning Receiver (RWR), Forward Looking InfraRed (FLIR), Global Positioning System (GPS) and Chaff/flare [2].
Both the indicated shift in operations and the installation of new Lynx systems put more emphasis on the need for improved usage information and better knowledge on Lynx mechanical loading.

The RNLN operates a fleet of 22 naval Lynx helicopters, in ship-based as well as in ground-based roles. As said above, main ship-based tasks are ASW and ASuW, whereas the ground-based helicopters operating from Naval Air Station De Kooy, in the northern part of The Netherlands near Den Helder, perform Training, Search And Rescue (SAR), Transport and Military Support missions.

This Lynx' multi-purpose capability makes operational planning a difficult job, especially when bearing in mind that airframe loading should preferably be equally distributed among the Lynx fleet in order to equally consume fatigue life capability.

RNLN maintenance policy, the NH90 and tie-bars

Being the RNLN maintenance authority, DNAEM is tasked to create optimal conditions for the support of it's naval aircraft, i.e. the P3-C Orion maritime patrol aircraft and the SH-14D Lynx helicopter.
With respect to the Lynx, DNAEM is confronted with a variety of technical challenges, that all are related to two primary missions: (a) to optimise Lynx maintenance and (b) to bridge an imminent gap between the Lynx and the NH90 helicopter, the latter helicopter type being the Lynx' successor entering RNLN service within the 2004-2009 timeframe.

Optimising Lynx maintenance means minimising total maintenance costs within safety and environmental restrictions until the last Lynx is removed from operational service without the need for operational restrictions. This has led to a so-called Smarter Maintenance policy [3] within the RNLN, in which a number of different technical projects are integrated addressing improved maintenance of airframe, engines as well as other rotating parts.
Bridging the gap means that enough flight hour capability remains available for the Lynx to continue full operational service until the new NH90 is able to take over all (and more) required missions.

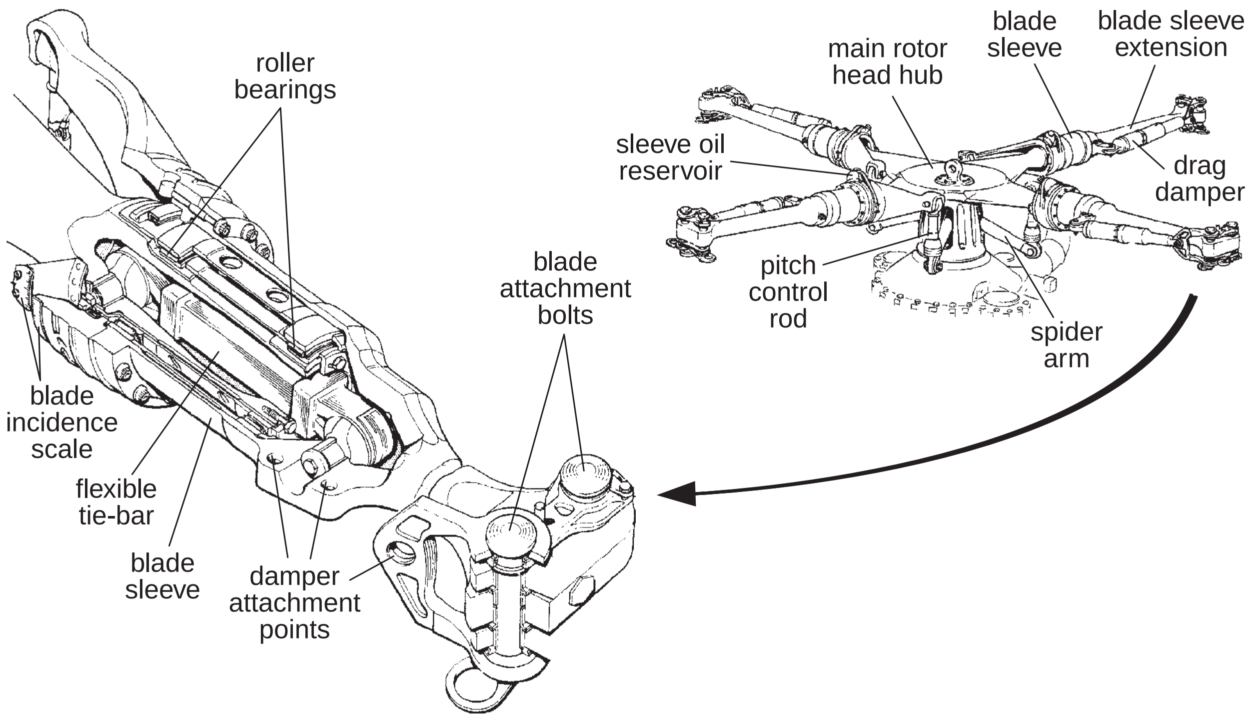

Fig. 2 Tie-bar

In September 1994 a fatal accident with a UK Lynx helicopter occurred in Germany as a result of a tie-bar[3] failure, see figure 2. Shortly afterwards, all Lynx operators faced a tie-bar inspection at relatively short flight hour intervals. This prescribed inspection is a heavy man-hour consuming effort and has great negative impact on operational availability. A way to minimise the inspection effort is monitoring main rotor rotational speed Nr, combined with Nr limit exceedance warnings.
Thus another functional requirement for a usage monitoring system was raised within the RNLN.
It was this last requirement that actually triggered the development of the AIDA-system, described in this paper.
Before describing the AIDA-system in some detail, some background will be given first on the rationale behind the need for such a unique and autonomous on-board data acquisition system for the RNLN Lynx.

Life Extension

A major issue within RNLN is the need for a Lynx life extension. Since 1976 the RNLN helicopter fleet has been used in a variety of roles. An ever increasing operational demand has led to a high degree of utilisation, consuming the 7,000 hours airframe fatigue life, that was issued upon delivery, in a rapid pace. To date, fleet leader airframes have acquired approx. 5,500 flight hours with an average yearly usage varying between 300 and 400 flight hours. This means that the 7,000 hours fatigue life limit of the Lynx airframe will be reached well before full deployment of the NH90.

For this reason, the RNLN felt the need for improved fatigue life monitoring of its Lynx airframes in the early 90's, and an administrative computerised Lynx usage monitoring data-base was set up. As a result of this, a detailed usage database comprising some 55,000 Lynx flight hours now exists at NLR for analysis purposes. As an example, a 30% life extension of the undercarriage attachment (the so-called sponson) has been achieved using this database by comparing actual usage information with design usage assumptions made by the helicopter manufacturer. Also, analyses were performed addressing the tail fold hinge frame and the main lifting frames under the gearbox.

It was realised, however, that additional measures would be necessary to bridge the NH90-gap under the current 7,000 hours airframe life restriction for the Lynx [1]. One such measure has been the performance of a structural survey on a number of fleetleader airframes. Another measure is the decision to instrument a number of fatigue critical locations of the Lynx airframe to generate actual loads information. The latter topic supported the development of a powerful on-board data acquisition system, now called AIDA.

Engine Cyclic Life Control

Another activity within this Smarter Maintenance policy was the implementation of fleetwide Cyclic Life Control (CLC) for the Rolls-Royce Gem-42 engines, installed in the Lynx. For this purpose, the engine manufacturer has specified component and engine

[3] The tie-bar is the connection element between the rotor hub and the blade

module retirement lives or TBO's (Time Between Overhaul) not only in flying hours but also in terms of actually flown and factored engine cycles. CLC can be described as on-line (in-flight) registration of LCF (Low Cycle Fatigue) engine damage accumulation, which is generally a relatively simple means to decrease hard time maintenance and thus operator costs [3].

In this process, projected conservative (i.e. severe) engine usage, that has been assumed by the engine manufacturer during design of the engine, can be replaced by information on actual service engine usage. An example of the benefit for the operator is shown in figure 3, showing Rolls-Royce prescribed Gem engine exchange rates (i.e. damage per flight hour) in comparison with actually measured RNLN exchange rates. It can be seen that RNLN usage of the Gem engine is between 33% (for the Gas Generator module) and 82% (for the Free Power Turbine module) less severe than assumed in the design. CLC is in operation within the RNLN since the early 90's on a sample monitoring basis, using four NLR developed cycle counters that are installed on a rotating basis within the 22 different airframes.

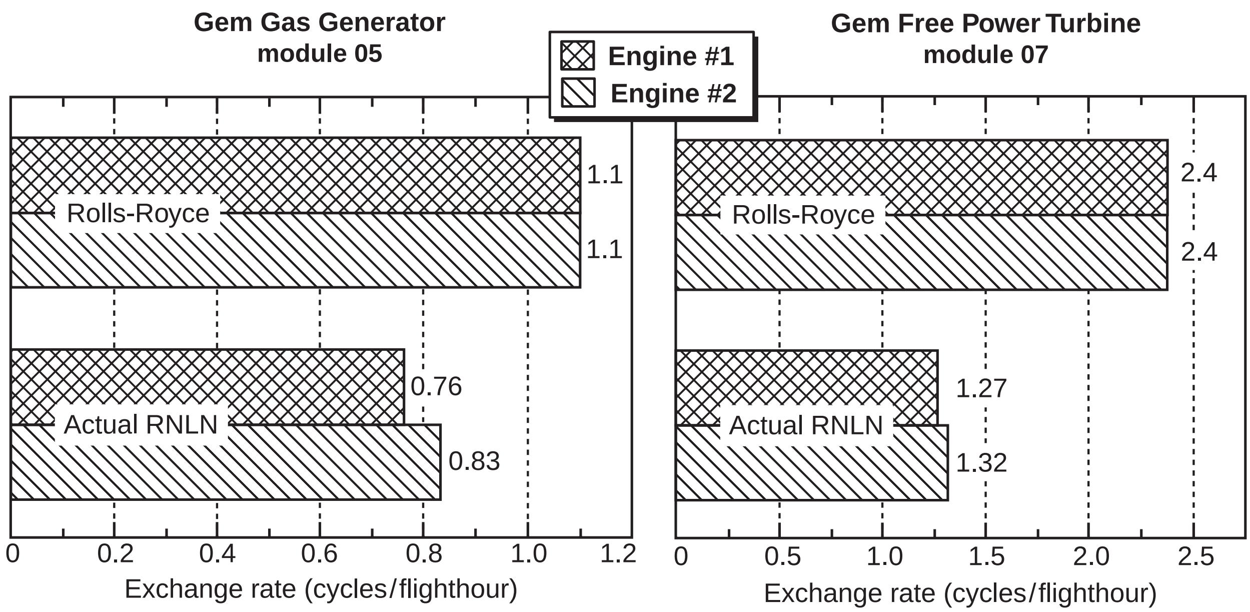

Fig. 3 Gem exchange rates for the Royal Netherlands Navy

To maximise CLC benefits the RNLN has recently decided to shift from CLC on a sample-monitoring basis (which process still incorporates certain maintenance penalties related to safety factors) toward CLC on a fleetwide basis enabling individual engine usage tracking (and thus eliminating those penalties). This CLC has been another reason to support the AIDA-system development.

1996 Structural Integrity Study

Initiated by the above considerations, the NLR was tasked by the RNLN to present the various available monitoring options to the RNLN in 1996. The study resulted in the following options list:

1. Only Nr (main rotor rotational speed) monitoring in each Lynx to cope with the tie-bar inspection issue, i.e. implementing a flexible, software adjustable 1-channel data-acquisition device, tailored to handle the newly prescribed inspection rules.

2. Nr monitoring with additional implementation of fleetwide Cyclic Life Control. This would require a 5-channel data-acquisition system in each Lynx, monitoring one rotational speed signal of the main rotor and 4 engine module rotational speed signals (2 per engine).

3. Nr monitoring, implementation of fleetwide Cyclic Life Control and direct airframe loads monitoring on a number of critical locations. This would require a more complex and powerful multi-channel recorder.

By the end of 1996, the RNLN decided to go for the 3rd option, covering the aforementioned goals of projected airframe life extension, fleetwide CLC and main rotor monitoring. A programme was started with NLR to define functional requirements for the multi-channel recorder.

Fig. 4 AIDA-recorder

The AIDA-system

As a result of aforementioned programmes the AIDA requirements were defined. In the paragraphs below, descriptions will be given of AIDA functionalities, software (data processing) procedures, hardware components, and the necessary aircraft modification effort.
It lies outside the scope of this paper to address all specified tasks in detail here, as well as to discuss other important AIDA features such as physical requirements (dimensions, weight, mounting, connectors etc.), detailed aircraft integration topics, data storage capacity, data transfer, data presentation, reporting, CPU capacity, configuration management, and off-line processing by ground station software. For more information on these topics, reference is made to the literature [4].

AIDA Functionalities

The AIDA-system requirements listed a rather extensive capability of conditioning, processing and storing data from 15 analog and 2 discrete signals, divided into the following signal types:

– 9 analog (low and high level) signals
– 5 tacho-generator signals
– 1 synchro signal
– 2 discrete signals.

The 17 signals are fed to the AIDA-recorder, shown in figure 4, where a much larger number of 39 different tasks is running real-time. A survey of the signal types and associated data-handling processes is shown in table 1 [4]. The various processes can be separated into the following task types:

1. Data reduction tasks that monitor and process the signals with standard algorithms like TT [4] , SPTT [4], SPTTS [4] and TATL[4], with subsequent storage of data into memory. The SPTTS algorithm, as an example, will search the load trace for successive peaks and troughs and will store them together with time stamps and momentary values of any slaved signals, see figure 5 for a schematic. Though these tasks are performed at high sampling rates, they accomplish a significant data reduction without loss of important fatigue loading information.

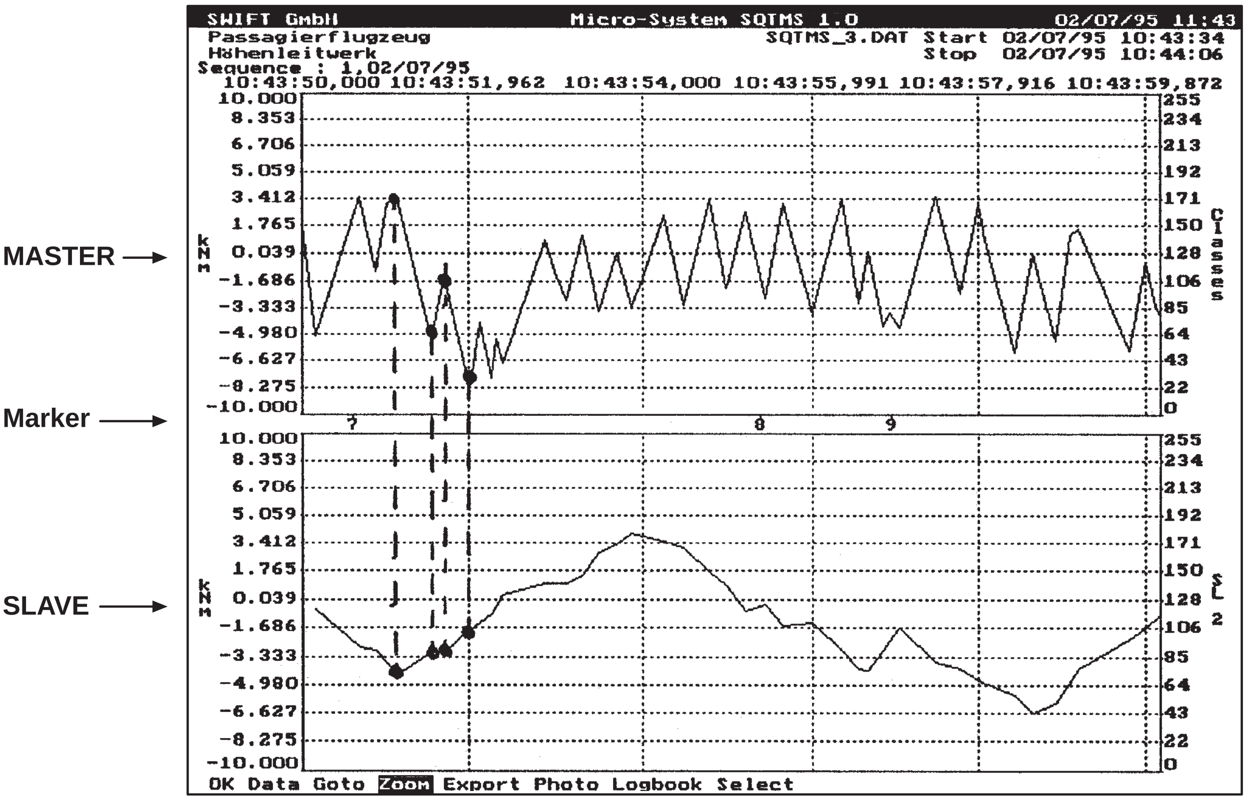

Fig. 5 Master/Slave relation

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[4] TT: Time Transient; SPTT: Sequential Peak and Trough with Time; SPTTS: Sequential Peak and Trough with Time and Slave; TATL: Time At Trigger Level

Signal	Description	Data Processing	Purpose
1	Main rotor RPM Nr	• SPTTS • Level crossing detection and audio warnings if: 60%<Nr<95% Nr>111.5% Nr>115.8% Nr>100 → Nr<10% • System integrity	• Nr history registration • Pilot safety & Nr exceedance registration • AIDA-system serviceability
2 4	High pressure compressor speed engine 1 & 2	• SPTT • TATL • System integrity	• Engine cyclic life control • Recording of actual engine hours • AIDA-system serviceability
3 5	Free power turbine speed engine 1 & 2	• SPTT • System integrity	• Engine cyclic life control • AIDA-system serviceability
6	Indicated air speed	TT	• Usage spectrum determination
7	Bank angle	SPTT	• Usage spectrum determination
8,9	Engine torque 1 & 2	SPTTS	• Usage spectrum determination
10 11 12 13	Sponson strain 1, 2, 3 & 4	• SPTTS • TT	• Loading spectrum of sponson • Helicopter weight used in usage spectrum determination • AIDA-system serviceability
14,15	Spare 1 &2	SPTT	• Ad-hoc investigations
16	Weight on Wheels	• Event count & event duration • System integrity	• Usage spectrum determination
17	Radalt low-limit indication	• Level crossing detection • System integrity	• Pilot safety
	Various	• Memory full • AIDA CPU working	• AIDA-system serviceability

Table 1 Summary of AIDA-recorder signals and tasks

2. Level crossing detection tasks that monitor the signals to check whether a pre-defined level is crossed in a certain direction, i.e. upwards or downwards. If so, audio/visual warnings will be given and relevant information will be stored into the AIDA memory. This type of tasks may be considered a safety issue for the helicopter and it’s crew. An example of this task is main rotor Nr overspeed or underspeed monitoring with associated audio/visual warnings.

3. Event count and event duration tasks. This task type provides signal monitoring, counts the number of times that a signal reaches a certain pre-defined level and determines the time duration that this signal is at this pre-defined level. These tasks provide direct compact event information without a further need for processing. The amount of data is significantly reduced compared to complete signal measurement in time. An example of this task is the Weight-on-Wheels (WoW) task, separating flight and ground events.

4. System integrity tasks, which can be divided into the following two types:
   – Built In Test (BIT), carried out automatically by the AIDA-recorder at start-up to verify the status of the AIDA-recorder.
   – System integrity checking algorithms that continuously monitor various signals during AIDA-recorder operation and check whether a pre-defined malfunctioning condition is met. If so, signal(s) and/or total system integrity is considered questionable

AIDA Data processing

Measurement data is generated and stored in the AIDA-recorder during operational service of the helicopter. This data is downloaded from the AIDA-recorder at periodical intervals and is subsequently sent to a central data processing facility at RNLN Naval Air Station De Kooy for storage and post-processing in a host station computer. If desired, this may occur after each flight. AIDA memory capability is designed to contain measurement data for appr. 100 flight hours.

Data integrity [5] will be established after duplication of basic (raw) measurement data in the host station computer, followed by valid-data data storage in a master data base. This master data base will then serve as the major RNLN tool for:
- determination of the RNLN Lynx usage spectrum.
- engine Cyclic Life Control recognising actually flown engine cycles.
- airframe fatigue life extension.

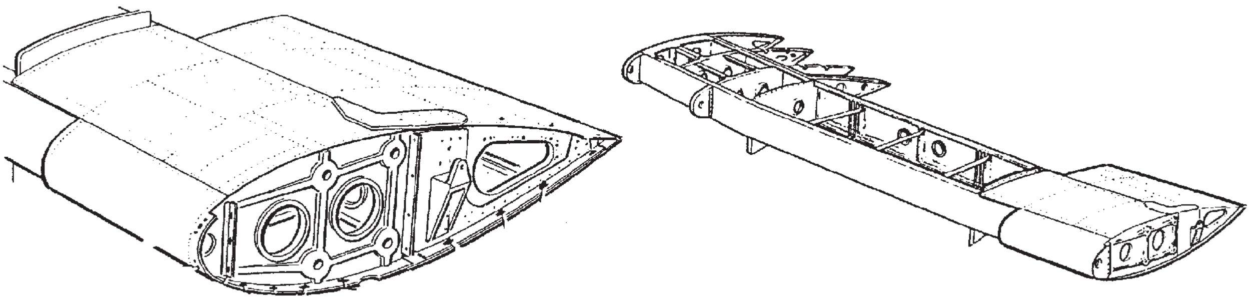

Fig. 6 Sponson

Sponson example

Referring to the fatigue life extension issue, an important structural element of the Lynx airframe is the sponson, i.e. the undercarriage attachment beam, see figure 6. In the design of the sponson structure, the helicopter manufacturer has assumed a certain load spectrum, and to account for usage variability, penalty factors have been applied. Because sponson loads are directly related to landings, certain estimates are incorporated in the fatigue life calculations addressing assumed statistics on landing weight, sinking speeds, landing type (i.e. on land or on deck) and forward speed upon landing (i.e. running landing).

Running landings are significant because the RNLN Lynx variant has main undercarriage wheels that are not positioned in flying direction. This means that significant (torsional) sponson loads will be introduced during a running landing that may serve as an indication for the occurrence and the severity of such a running landing. For this purpose, the AIDA-recorder will monitor the output of 4 strain gauges on port and starboard fore and aft sponson spars, enabling automatic:

- determination of momentary helicopter weight upon each landing through measuring sponson spar bending.
- discrimination between land- and deck-landings by recognising harpoon engagements (the harpoon is a centrally located locking device that is triggered when landing on a grid).
- determination of occurrence and severity of each (running) landing by measuring whether additional torsional loads are introduced in the sponson beam structure.

This sponson monitoring function is considered a good illustration of how the RNLN expects to generate valuable usage and loads data in the effort to gain extra sponson life. AIDA has a spare capacity for possible campaign measurements on other important structural elements, such as the tail structure and the main lifting frame. It is foreseen that this additional AIDA potential will be needed in future life extension discussions between RNLN and GKN Westland.

AIDA-system components

The complete AIDA-system comprises the following hardware items: AIDA-recorder (airborne equipment), ground support station, host station, PC-card, break-out box[5] and test system.
The AIDA-recorder is the heart of the AIDA-system. It carries out all tasks that have been defined and stores the data into memory. The ground support station (notebook computer) controls the AIDA-recorder. It enables the operator to communicate with the AIDA-recorder in order to transfer data, adjust channel settings, display data, to start or to stop measurements, etc. Data will be transferred via either a PC-card (S-ram) or a RS-232 port and will be sent to a central facility, where all data will be processed on a so-called host station (personal computer). Furthermore, a break-out box and a test system is available for maintenance purposes.

The aircraft modification

The Lynx aircraft modification for AIDA has been designed and developed, and will be authorised and implemented by the RNLN. The modification is based on a standard

[5] Break-out box: a device to provide a signal draw-off capability for each signal without the need to remove the AIDA-recorder from the aircraft

RNLN Lynx version with some additional modifications covering sensors for FLIR, RWR, GPS and systems for Chaff/flare, four-bag flotation system and engine usage monitoring.
With the aircraft in this configuration, almost all necessary AIDA sensors are already available, including shelf-assemblies to accommodate the AIDA-recorder. Only the strain gauges for the sponson load measurements had to be installed as an extra feature. A significant point is the connection of the various sensor outputs to the resp. AIDA-recorder input circuits, applying high frequency screened cable whenever needed. This modification step was carried out with maximum use of existing terminal blocks and was responsible for the largest consumption of man-hours required for the aircraft modification.
In total, appr. 3 weeks are needed to perform an entire AIDA Lynx modification.

Supplier Selection

The RNLN was confronted with the problem that no tailored (Commercially-Off-The-Shelf) equipment was available. Therefore, a RNLN/NLR technical team was formed to generate functional requirements for the AIDA-recorder, to support the construction of a formal RNLN Request For Quotation, and to evaluate the proposals received from industry. All this was done in a rather short time frame. The RFQ was sent out by December 1996, industry proposals were received in February 1997 and the final order to Swift GmbH (Reinheim, Germany) was given in June 1997.

Certification Aspects

AIDA will be used as a basis for Lynx maintenance interval calculations in the future, and will alert crew members in-flight if certain limits are exceeded. Certification procedures for typical modifications controlled by the RNLN are illustrated in figure 7. It is shown that not less than 12 different documents are to be provided for certification purposes.

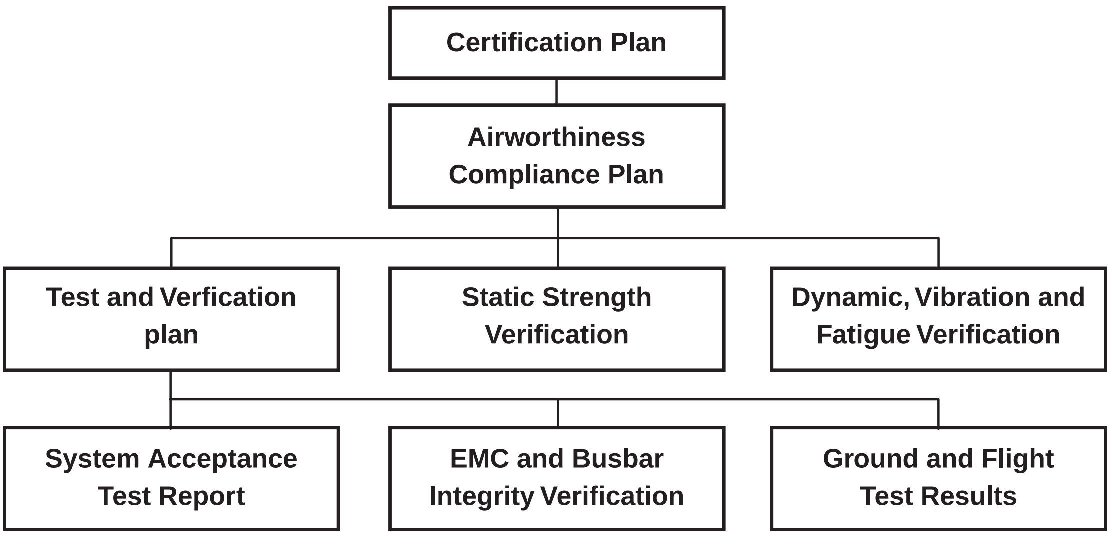

Fig. 7   RNLN-modification certification plan

At an early stage, it was realised that the embodiment of the AIDA certification process would be a heavy burden for the RNLN engineering people. It was therefore necessary to issue a dedicated certification contract to the NLR Helicopter Dept. to perform this task. Being initiated in December 1997, the certification task is expected to be finished in the second half of 1998.

Concluding Remarks

The intention of this paper is to describe the many aspects connected to implementation of a complex set of requirements for in-flight data acquisition in the RNLN Lynx helicopter.
The expectation to decrease maintenance costs, to extend airframe fatigue life and to relieve tie-bar related maintenance penalties, have all led to the RNLN point of view that funding an investment of AIDA-size was considered worthwile.

Acknowledgements

It must be underlined that the introduction of AIDA within the RNLN would not have been accomplished in such a short time frame, and with such a high quality level, without the valuable contribution of a small number of dedicated people of Swift GmbH, NLR and RNLN.

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