Physics-based FRR algorithms have been developed by NLR to calculate the severity of flight regime recognition (FRR) in a transparent way. The basis of many of NLR’s structural integrity concepts is the flight regime recognition (FRR) for the Chinook, the Apache and the NH90 Helicopters by collecting flight administration data (i.e. mission duration, number and type of landings, mission equipment, mission profile) and linking this to measured flight loads and usage data, it becomes possible to calculate damage per flight segment in mission events.

FRR is the basic tool for structural integrity tools such as PROUD and IDEAS.

Transport Aircraft Holmes

The C-130 “Hercules” fleet of the RNLAF is used to perform a different role than originally anticipated at the time of acquisition. Out of area operations such as those performed under the ISAF (International Security Assistance Force) severely stress the aircraft and adversely affect the service life of the airframe. The RNLAF has developed a tool for damage assessment using measured flight loads and usage data, the Holmes mission profile can be generated in detail, including specification of internal or external loads. The user specifies the aircraft weight, the detailed mission types descriptions and associated mission mass. Holmes then calculates the severity of the assumed usage scenario, relative to a specific reference usage, which typically is the standard Dutch peace-time usage. With this the operator can project the future footprint and estimate the type and level of airframe degradation for future out of area deployments.

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**Introduction**

The National Aerospace Laboratory NLR maintains long-standing strategic relationships with weapon system managers of various arms around the world to generate joint projects and competitive advantages in the fields of aviation safety and maintenance, sustained operational availability, flight safety and structural integrity. Within the context of international arms transfers and shrinking budgets, Force Life Management of military aircraft is an area in which NLR has decided to make a key play.

This brochure presents outlook and performance information. It highlights NLR focus areas and outlines recent innovation developments.

**Work areas**

NLR’s focus in the Management areas covers six types of aviation assets. They include flex wing aircraft, such as fighters, trainers, transport and marine patrol aircraft, as well as weapon systems.

The NLR’s focus and capabilities can generate quantifiable maintenance cost reductions for weapon system managers. Demonstrated benefits exist in a variety of maintenance contexts and situations to such an extent that NLR’s approach of failure inspection intervals, the introduction of better inspection methods, the avoidance of failure mechanisms that result from specific operational usage phases underlies the optimization of operational procedures to achieve damage assessment.

**The four levels of Force Life Management**

Force Life Management of NLR is the framework of technical activities that are performed throughout the project life of a weapon system to maintain an operational capability. These activities are carried out in the area of maintenance costs, availability and flight safety.

Four main levels of different stakeholders can be distinguished:

- Level I: Force Life Management (FLM) is defined as the management of operational system availability, minimum maintenance costs and unimpeded flight safety. The stakeholders are the weapon systems, the operator and the weapon system manager.
- Level II: Unlike Level I, FLM is associated with obtaining key technological data from the weapon system, such as percentages, remaining useful life numbers, fatigue life indices, various flight severity indices, etc. The stakeholder of Level II is the maintenance engineer.
- Level III: It is associated with determining key technological data from the weapon system, such as percentages, remaining useful life numbers, fatigue life indices, flight severity indices, etc. The stakeholder of Level III is the maintenance engineer.
- Level IV: This relates to the research organisations that support the weapon system manager to achieve the higher levels II and III.

- Level I: In this respect, Level I is associated with the weapon system manager to achieve the higher levels II and III.
- Level II: The highest application level of Level II, associated with determining key technological data from the weapon system, such as percentages, remaining useful life numbers, fatigue life indices, flight severity indices, etc. The stakeholder of Level I is the weapon system manager.
- Level III: It is associated with obtaining key technological data from the weapon system, such as percentages, remaining useful life numbers, fatigue life indices, flight severity indices, etc. The stakeholder of Level III is the weapon system manager.
- Level IV: It is associated with the weapon system manager to achieve the higher levels II and III.

**FIGHTER AIRCRAFT**

F-35

The F-35 Lightning II is the most advanced multirole fighter in the world and has been designed to meet a wide range of international air combat requirements. The F-35 Lightning II is a fifth-generation fighter aircraft that features a stealth design, advanced avionics, and a host of other capabilities.

**HELICOPTER LOAD & USAGE MONITORING**

The helicopter fleet of the Royal Netherlands Air Force (RNAF)/Netherlands has served as the development field for innovative Force Life Management concepts. Flight regime Recognition (FRR) algorithms have been developed for the Chinook, Apache and NH90.

For the fatigue-critical locations and components the associated damage indices per flight regime have been derived. The NLR currently conducts FRR-based load and usage monitoring programmes for these three helicopter types.

**PROUD**

The Flexible, operator-oriented fatigue damage prognostics tool has been developed to plan and predict the logistics footprint and the required spares inventory, maintenance personnel and warehousing needs in the course of out-of-arm deployments.

**ODAT**

The NLR has developed a prototype of a so-called ‘Operational Damage Assessment Tool’ that can be used to assess the severity of weapon fatigue cracks in the primary airframe structure of helicopters. ODAT will facilitate the decision whether or not to fly, and for how long and under what operational circumstances, with the damage that is present. In the case of out-of-arm operations, the required maintenance actions can be defined (or deferred) for more suitable moments and locations.

**AIDA**

AIDA is a multi-channel infrared data acquisition system, that the NLR has developed for the Lynx helicopter to measure and process the main rotor speed engine, the rotor speeds in various modules, the blade attitude and the spinning rotor speed. Since its first flight in the summer of 2003, the AIDA (Advanced Infrared Data Acquisitions System) has been tested on various Lynx helicopters. The AIDA system is designed to detect and measure the thermal response of the Lynx helicopter to the external environment.

**INTEGRATED DATA MANAGEMENT HELIUM AND RAVIOLI**

HDLN is a secure database archive, containing all relevant helicopter flight and loads/usage data generated by RNAF helicopters, covering Chinook, Apache, Cougar and the NH90. All data from all sorts of data sources can be handled (FAME, HOME, flight admin data etc.), HDLN is an XML database, with XPath and XQuery access to the stored data. Using XML documents as input for the data storage provides many advantages, such as easy conversions and from XML documents, well defined syntax using XML Schemas, excellent support in e.g. Java, and for Apache AIDA, RAVIOLI can be seen as the GUI on top of HELIUM. MADRIX (Mounting, Analysis, Visualization of aircraft lifecycle information) can be seen as an ‘IT Facility’ for the military operator with an innovative, fully integrated tool kit for the analysis of usage, loads and maintenance data in a web-based application of data and information management, searching and reporting of data.

**NH90 HISDES**

The main helicopter HISDES (HIVitality Systems Data Exchange System) of NH Industries has recently received official position in the NH90 HISDES (HIVitality System Data Exchange System) HISDES will support the weapon system manager on different levels.

(i) occurrence and incidents reporting,

(ii) RAM data collection and analysis

(iii) usage and maintenance monitoring for structural integrity purposes.

**Force Life Management**

NLR’s role in supporting the operator with operational availability, flight safety and maintenance is to:

- provide the operator in the pursuit of optimal weapon system management. The NLR has demonstrated success in this respect by applying the Force Life Management (FLM) concept to the NH90.

**Measurement**

A model of many DEIMOS implementations is the measurement of flight parameters and operational loads and usage data. The NLR has developed a comprehensive measurement campaign for numerous weapon systems. Examples are:

- F-16 (NLR)
- S-300, UH-60 (DAR)
- CH-47 Chinook (NLR)
- AH-64 Apache (NLR)
- P-3 Orion (DAR)
- CH-47D Chinook (Acra)

**Analysis**

For the processing and analysis of the measured data, numerous calculation procedures and algorithms are in use within the NLR, such as: operational load monitoring, crack growth modeling, loads verification, FEM analysis, calculation of dynamic behavior, etc. Measured and calculated data are on goal itself. They are elements that are used in incorporated within FLM concepts, aimed at supporting the weapon system manager in the overall control of weapon system management. The NLR has developed numerous innovative approaches, such as:

- Proprietary Flight Regime Recognition procedures for Chinook, Apache and NH90

**Application**

- **PROUD**: for the prognosis of future Chinook damage accumulation
- **FLATE**: to support the operator with an efficient tool for simple Individual Aircraft Tracking
The National Aeronautics and Space Administration (NASA) maintains strong strategic relationships with aerospace system managers of various aeronautics around the world to generate joint projects and competitive advantages in the fields of aeronautics and space transportation, sustainable operations, and system assurance. The National Aeronautics and Space Administration (NASA) is the US federal agency responsible for the civilian space program and for aeronautics and aerospace research. The NASA Mission Statement is "To understand and explore our solar system with robotic spacecraft, and to advance the study of Earth, the environment, and space through a FREE program of research and education."

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**Work areas**

The NLR's Focus on Management activities cover four types of helicopter: they include fixed wing aircraft such as fighters, trainers, transport, and marine patrol aircraft, as well as various types of helicopter. The NLR's focus and capabilities can generate quantifiable maintenance credits for the weapon system manager. Demonstrated benefits with respect to a maintenance cost and profit margin results in a longer reconstruction of the fleet, the achievement of longer inspection intervals, the introduction of better inspection methods, the avoidance of failure mechanisms that result from specific operational usage (such as adverse conditions) and the optimization of operational procedures to alleviate damage accumulation.

**The four levels of Force Life Management (FLM)**

Referring to the management of logistics for the development of technical solutions that are performed throughout the projected lifetime of a weapon system to maintain or improve its operational capability. These activities are carried out in the areas of mission, combat, availability, budgeting, and sustainment.

- Level I: associated with obtaining key information on the fielded weapon system and associated maintenance equipment. The cooperation must be aimed at establishing a robust operational support concept that works effectively and supports the weapon system manager to achieve the higher levels II and III.
- Level II: associated with the development of models used to incorporate a weapon system into the operational processes. The cooperation must be aimed at establishing a robust operational support concept that works effectively and supports the weapon system manager to achieve the higher levels IV.
- Level III: associated with the development of technical solutions that are performed throughout the projected lifetime of a weapon system to maintain or improve its operational capability. These activities are carried out in the areas of mission, combat, availability, budgeting, and sustainment.
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**For the F-16 Lightning-II structural load monitoring of the RNLAF/F-16 fleet has been carried out by NLR since the early nineties. More recently, a new fleet wide innovative fatigue management system was developed by NLR involving an existing pilot dedicated system with load and usage monitoring functional units. Key features of this so-called FLYM system (Fatigue Monitoring in the Flight Control System) enable the measurement in five locations two measuring wing bending two measuring tail loads and one measuring fuselage bending. Additionally, a comprehensive F-16 load and usage monitoring database has been implemented at NLR in a secure environment, for storing, managing and processing the raw measurement data.**

**F-35**

As a domain expert within the Dutch F-35 consortium, NLR has been involved in the design and implementation of the F-35 Lightning II's fatigue board program and health management system. In particular NLR was involved in fleet health management, flight reiter, failure resolution, and knowledge discovery systems.

**FIGHTER AIRCRAFT**

**F-16**

The helicopter fleet of the Royal Netherlands Air Force (RNLAF) has served in the development field of innovative Force Life Management concepts. Flight regime recognition (FRR) algorithms have been developed for the Chinook, Apache and NH90. For the fatigue critical locations and components the associated damage indices per flight regime have been derived. The full concept contains FRM-based loads and usage monitoring for the following future weapon system types.

**PROUD**

The flexible, operator-centric fatigue damage prognostics tool has been developed with the aim of using the NLR's experience to develop an easy-to-use tool for the operator in the pursuit of optimal weapon system management. The PROUD tool is to be used in the early design phase of a weapon system to enable the operator in the pursuit of optimal weapon system management. The tool is to provide the operator with a graphical representation of the weapon system's current fatigue state and to allow the operator to select the appropriate actions to be taken to improve the weapon system's fatigue life.

**HELIODATA**

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**HISDES**

**ODAT**

The NLR has developed a prototype of a so-called Operational Damage Assessment Tool (ODAT) that can be used to assess the severity of various fatigue cracks in the primary airframe structure of helicopters. ODAT will facilitate the decision whether or not to fly, and for how long, and under what operational circumstances, with the damage that is present. In case of out of use operations, the required maintenance actions can then be deferred or performed at a more suitable moment and location.

**AIDA**

AIDA is a multi-channel wireless data acquisition system that the NLR has developed for the Lynx helicopter to measure and process the main rotor speed, the engine's speeds in various modules, the blade attitude and the optronic and sensor data. Since its fleet wide introduction in the Lynx fleet of the Royal Netherlands Navy (RNLN), AIDA has been the basis for the fatigue life analysis of the mainframe, the optronics and the engine modules. NLR has generated proven maintenance credits and has provided a very useful flight test data bridge the operational gap between the phase-out of the Lynx and the introduction of the NH90 in the RNLN.

**Force Life Management (FLM)**

**F-16 Lightning-II**

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**FIGHTER AIRCRAFT**

**F-35**

Initial load monitoring of the BOFAF-16 has been carried out by NLR since the early nineties. More recently, a small fleet wide initiative fatigue monitoring system was developed by NLR including an existing pilot debriefing system with loads and usage monitoring functionalities. Max features of this so-called cockpit system (Fatigue Monitor on Air Combat Evaluation System) in the capability to measure stress in five locations: two measuring wing bending, two measuring tail loads and one measuring fuselage bending. Additionally, a comprehensive F-16 loads and usage monitoring database has been implemented at AFRL in a secure environment, for storing, managing and processing the raw measurement data.

**F-25**

As domain expert within the Dutch F16 consortium, NLR has been involved in the design of the implementation of the F-25 signature risk lab program and health management system. In particular NLR was involved in fleet health management, flight re-conversion, failure resolution and knowledge discovery systems.

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**HELICOPTER LOAD & USAGE MONITORING**

The helicopter fleet of the Royal Netherlands Air Force (RNLAF) has served as the development field for innovative Force Life Management concepts. Flight regime Recognition (FRR) algorithms have been developed for the Chinook, Apache and NH90.

For the fatigue critical locations and components the associated damage indices per flight regime have been derived. The F-35 currently carries F18 based loads and usage monitoring software for these flight regimes.

**PROUD**

The Fitness-oriented, operator-oriented fatigue damage prognosis tool has been developed in order to assist the NLR to estimate the severity of future usage scenarios. The tool is to particularly predict and validate the logistical footprint and the required spares inventory, maintenance personnel and warehousing needs in the case of out of area deployments.

**ODAT**

The NLR has developed a prototype of a so-called ‘Operational Damage Assessment Tool’ that can be used to assess the severity of various fatigue cracks in the primary airframe structure of helicopters. ODAT will facilitate the decision whether or not to fly and how long and what operational circumstances, with the damage that is present. In the case of out of area operations, the required maintenance actions can then be deferred or performed at a more suitable moment and location.

**AIDA**

AIDA is a multi-channel wireless data acquisition system that the NLR has developed for the Lynx helicopter to measure and process the main rotor speed, the engine speed and in various modules, the blade attitude and the response speed of the engines. Since first flight wide introduction in the Lynx of the Royal Netherlands Navy (RN), AIDA has been the basic tool for the fatigue life extensions of the mainframe, the spar and the engine modules. NLR has generalized proven maintenance criteria and has seen as very effective F16 technique. The improved operational usage characteristics and the introduction of the OODA in this RN.

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**INTEGRATED DATA MANAGEMENT**

**HELICOM**

HELICOM is a secure database which contains all relevant helicopter flight and usage data generated by RNLAF helicopters, covering Chinook, Apache, Cougar and the NH90. All data from all sorts of data sources can be handled (F18, F35, flight data analysis etc.). HELICOM is a SQL database, with PHP and MySQL access to the stored data. Using XML documents as input for the data storage provides many advantages, such as easy customization and from SQL documents, well-defined syntax using XML Schemas, excellent support in e.g. Java and PHP. Ahmed, RAVOI on can be seen as the GUI of this HELICOM. RAVOI (RAVolutionary Analysis, Visualization and Distribution) of AHF aircraft lifecycle information can be defined as an ‘IT Facility’ for the operator with an intelligent, fully customised tool for the analysis of usage, loads and maintenance data in various applications of mission storage, visualisation and reporting of data.

**NH90 HISDES**

The maritime helicopter NH90 has recently entered service in The Netherlands and the NH90 integrated helicopter usage and data storage system (HISDES) can be seen as a digital weapon system for storing, managing and analysing data. HISDES will support the weapon system manager on different levels: (1) occurrence and incidents reporting, (2) RAM data management and analysis and (3) load & usage monitoring for structural integrity purposes.
Physics-based FRR algorithms have been developed by NLR to calculate the severity of projected Chuiko usage scenarios in terms of airborne fatigue. It is powerful in that any possible future Chuiko mission profile can be generated in detail, including specifications of internal or external loads. The user specifies the aircraft weight, the detailed mission type descriptions and associated mission risk. PROUD then calculates the severity of that assumed usage scenario, relative to specific reference usage, which typically is the standard Dutch peacetime usage. It is up to the operator to compare this with the reference usage and estimate the type and level of airborne degradation for future out of area deployments.

PLATO

Using a graphical tool to present a fixed-wing aircraft mission, in detail, it becomes possible for the operator to calculate the fatigue damage severity of any imaginary mission profile. The input for PLATO mission profile (FAeros (TTL)) is a graphical representation of a mission. Per flight segment the momentary airspeed, altitude and aircraft weight can be specified. PLATO then calculates the amount of fatigue damage, which can either be based on Miner’s rule (fatigue approach) or on crack growth (fatigue tolerance approach) for a variety of load sources, including gust loads, manoeuvres, full stop landings, touch & go’s, main Ground-Air-approach (GAA), etc. PLATO can also be used as the fixed-wing equivalent of PROUD for the helicopter community.

FRR is the basic tool for structural integrity tools such as PROUD and HOLMES for the Chinook, the Apache and the NH90 helicopter. By collecting flight administration data (e.g. mission duration, number and type of landings, mission equipment, mission profile and mission risk), this allows this to measured flight loads and usage data, it becomes possible to calculate damage per flight segment in mission event.

FLIGHT REGIME RECOGNITION

The basis of many of NLR’s structural integrity concepts is the ability to perform flight regime recognition (FRR) in a transparent way. Physics-based FRR algorithms have been developed by NLR.

PROUD

PROUD is an innovative tool for the military operator to estimate the severity of projected Chuiko usage scenarios in terms of airborne fatigue. It is powerful in that it is possible to define future Chuiko mission profiles that can be generated in detail, including specifications of internal or external loads. The user specifies the aircraft weight, the detailed mission type descriptions and associated mission risk. PROUD then calculates the severity of that assumed usage scenario, relative to specific reference usage, which typically is the standard Dutch peacetime usage. It is up to the operator to compare this with the reference usage and estimate the type and level of airborne degradation for future out of area deployments.

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FRR is the basic tool for structural integrity tools such as PROUD and HOLMES.

THE C-130 “ Hercules” fleet of the RNLAF is used in a much different way than originally anticipated at the time of acquisition. Out of area operations such as those performed under the ISAF flag in Afghanistan severely stress the aircraft and adversely affect the service life of the airframes. The RNLAF has developed a loads and usage monitoring system (national HOLMES Integrated Operational Monitoring & Evaluation System) that brings together measured flight data and flight administrative data from various sources. The collected information is used to compute the expected fatigue life of the critical areas of the aircraft. The HOLMES data management system is aimed to take informed decisions with regard to fleet life management.

HOW TO USE HOLMES

New missions and usage scenarios can be assessed in a transparent way. HOLMES currently monitors the loading and usage of the C-130 “ Hercules” fleet of the RNLAF in Afghanistan and Iraq. HOLMES also calculates damage per flight segment in mission event and provides calculated damage assessments that can be used to estimate remaining structural life and mission equipment.

Transport Aircraft

HOLMES

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SALSA

To facilitate the quick-look evaluation of operational loads, the NLR has developed a system called SALSA (SALSA: a miniaturized, stand-alone and autonomous 1-channel data acquisition system). It is a miniatureized, stand-alone and autonomous 1-channel data acquisition system to measure operational loads, such as strains, accelerations and temperatures. SALSA is fully autonomous and does not interfere with any aircraft system. The necessary certification effort for on-board use is a thorough five year testing and validation phase. This certification phase is needed to enable the installation of the system on board the aircraft.

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Physics based FRR algorithms have been developed by NLR. The basis of many of NLR's structural integrity concepts is the Flight Regime Recognition of PROUD for the helicopter community. Ground cycle, etc. PLATO can be seen as the fixed wing equivalent manoeuvres, full stop landings, touch & go's, main Ground - Air - approach) for a variety of load sources, including gust loads, manoeuvres, full stop landings, touch & go's, main Ground - Air - approach) and linking of internal or external loads. The user specifies the aircraft weight, mission profile can be generated in detail, including specification of internal or external loads. The operator then calculates the severity of that assumed usage scenario, relative to specific reference usage, which typically is the standard Dutch peace-time usage. With this information, the operator can project the logisticks footprint and estimate the type and level of airframe degradation for future out of area deployments.

**FLIGHT REGIME RECOGNITION**

The basis of many of NLR's structural integrity concepts is the ability to perform flight regime recognition (FRR) in a consistent way. Physics based FRR algorithms have been developed by NLR for the Chinook, the Apache and the NH90 Helicopter by collecting flight administration data (i.e. mission duration, number and type of landings, mission equipment, mission profiles) and relating this to measured flight loads and usage data, it becomes possible to calculate damage per flight segment or mission event.

**PROUD**

PROUD is an innovative tool for the military operator to estimate the severity of projected Chinoik usage scenarios in terms of airframe fatigue. It is powerful in that it can provide full mission profiles can be generated in detail, including specification of internal or external loads. The operator specifies the aircraft weight, detailed mission type descriptions and associated mission mix. PROUD then calculates the severity of that assumed usage scenario, relative to specific reference usage, which typically is the standard Dutch peace-time usage. With this information, the operator can project the logisticks footprint and estimate the type and level of airframe degradation for future out of area deployments.

PROUD is the basic tool for structural integrity tools such as PROUD and HISDES.