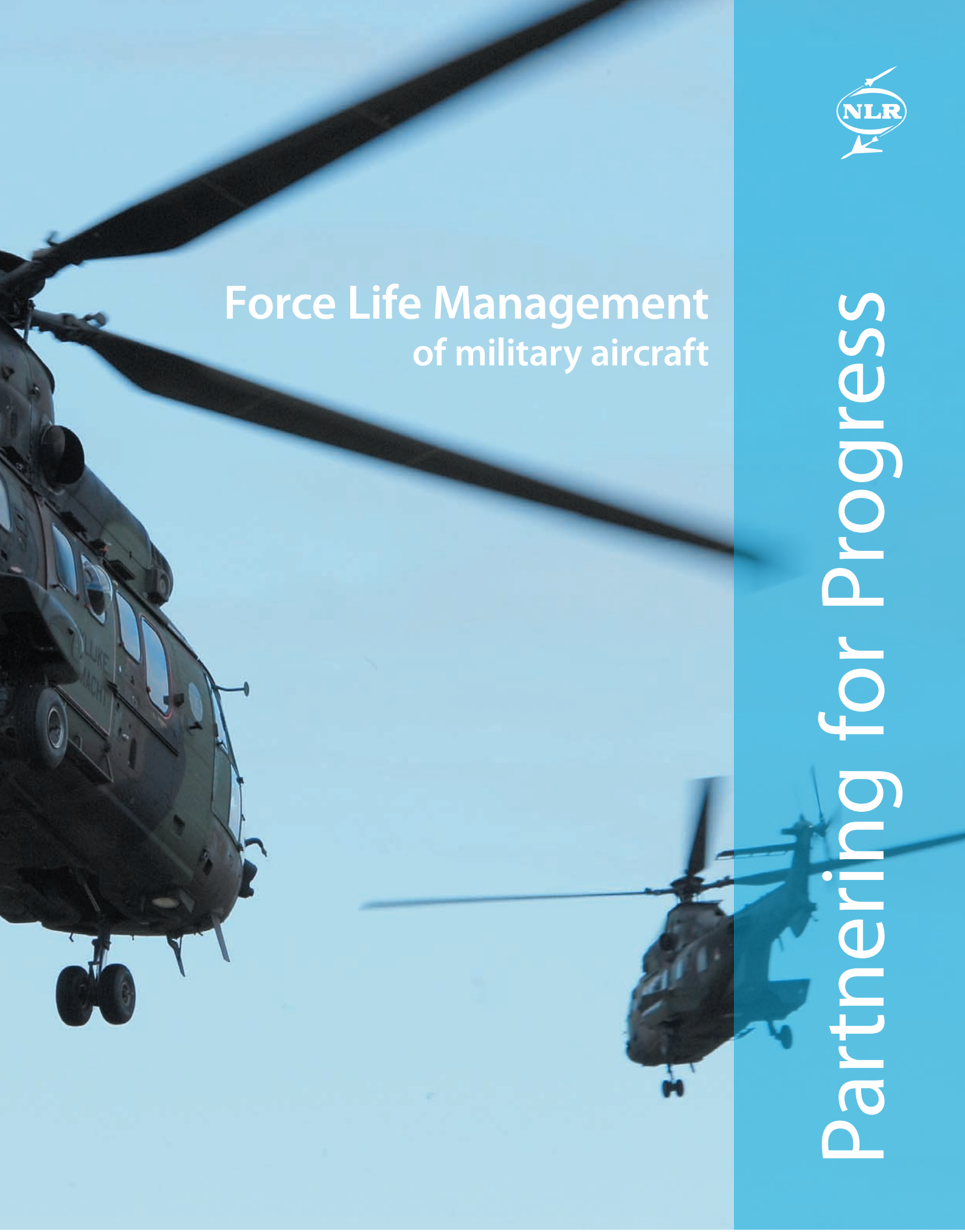


Force Life Management
of military aircraft

Partnering for Progress

***NLR** - Dedicated to innovation in aerospace*

Prognostics & Health Management
Performance Based Logistics
Condition Based Maintenance
Health & Usage Monitoring

Introduction

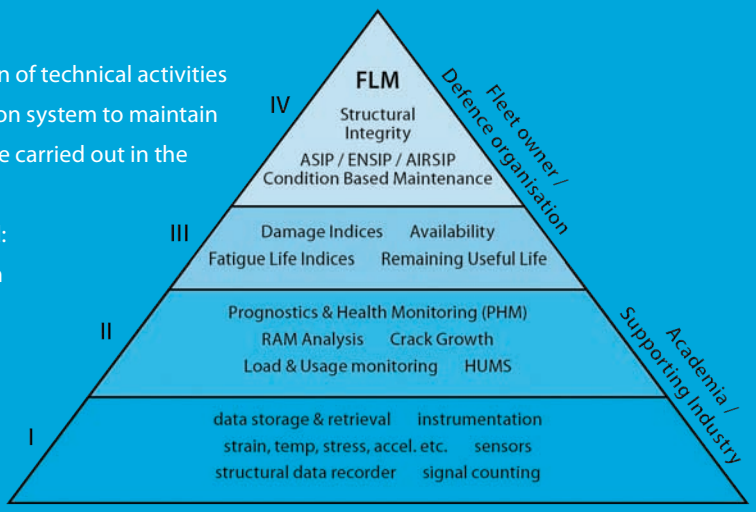
The National Aerospace Laboratory NLR maintains long term strategic relationships with weapon system managers of various air forces around the world to generate best practice and competitive advantages in the fields of airframe and engine maintenance and sustainment, operational availability, flight safety and structural integrity. Within the international context of aging fleets and shrinking budgets, **Force Life Management** of military aircraft is an area in which the NLR has the ambition to remain a key player.
This brochure presents some past and present performance. It illustrates NLR's focus areas and highlights some current innovative developments.

Work areas

The NLR's Force Life Management activities cover all types of military aircraft. They include fixed wing aircraft, such as fighters, trainers, transport and maritime patrol aircraft, as well as various types of helicopters.
The NLR's vision and capabilities can generate quantifiable maintenance credits for the weapon system manager. Demonstrated benefits with regard to maintenance costs and platform availability include longer on-wing periods of lifed items, the achievement of longer inspection intervals, the introduction of better inspection methods, the avoidance of failure mechanisms that result from specific operational usage characteristics and the optimization of operational procedures to alleviate damage accumulation.

The four levels of Force Life Management

Force Life Management (FLM) can be considered as the collection of technical activities that are performed throughout the projected lifetime of a weapon system to maintain or improve its required operational capability. These activities are carried out in the area of tension between cost, availability and safety.
Four main levels and different stakeholders can be distinguished:



- Level IV represents the high level FLM objectives of maximum operational system availability, minimum maintenance costs and uncompromised flight safety. The stakeholder of FLM Level IV is the fleet owner and/or maintainer.
- Level III is associated with obtaining key numerical management data like availability percentages, remaining useful life numbers, fatigue life indices, various flight severity indices, etc. The stakeholder of FLM Level III is the maintenance engineer.
- Level II serves to generate the Level III figures. Underlying concepts have to be implemented, such as PHM (Prognostics & Health Management), CBM (Condition Based Maintenance), RCM (Reliability Centered Maintenance), ILM (Intelligent Load Monitoring), IAT (Individual Aircraft Tracking), etc. The stakeholders of FLM Level II are the industry, academia and/or the research organisations that suppor the weapon system manager to achieve the higher Levels III and IV.
- Level I is the lowest application level of FLM, associated with instrumentation, sensors, signal generation and storage, on-board algorithms for real-time signal analysis, etc. Again, the stakeholders are the industry, academia and/or the research organisations that are responsible for the development and adequate implementation of the higher FLM Levels.

FIGHTER AIRCRAFT

F-16

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 monitoring system was (co-)developed by NLR by adapting an existing pilot debriefing system with loads and usage monitoring functionalities. Main features of this so-called FACE system (Fatigue Analyser & air Combat Evaluation system) is the capability to measure strains at 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 NLR in a secure environment, for storing, managing and processing the raw measurement data.

F-35

As domain knowledge expert within the Dutch PHM consortium, NLR has been involved in part of the design and implementation of the F-35 Lightning-II off-board prognostics and health management system. In particular NLR was involved in fleet health management, flight re-creation, failure resolution and knowledge discovery systems.

Force life management is: *Measurement* → *Analysis* → *Application*

A vital part of many FLM implementations is the measurement of flight parameters and operational loads and usage data. The NLR has developed and conducted on-board measurement campaigns for numerous weapon systems. Examples are:

- F-16 (FACE)
- WHL Lynx SH-14D (AIDA)
- CH-47D Chinook (Acra)
- AH-64D Apache (MSPU)
- P-3C Orion (SDRS)
- C-130H (Spectrapot, FDAMS)

Additionally, the NLR has developed a small stand-alone digital signal collector dubbed 'SALSA', for the flexible, generic and autonomous in-flight measurement of loads data.

For the processing and analysis of the measured data, numerous calculation procedures and algorithms are in use within the NLR, such as signal counting techniques, modal analysis, static strength calculations, crack growth modeling, loads verification, FEM analyses, calculation of dynamic behaviour, etc.

Measured and calculated data are no goal in itself. They are elements that are to be incorporated in meaningful FLM concepts, aimed at supporting the operator in the pursuit of optimal weapon system management. The NLR has developed numerous innovative approaches, such as:

- Proprietary Flight Regime Recognition procedures for Chinook, Apache and NH90
- PROUD, for the prognosis of future Chinook damage accumulation
- PLATO, to support the operator with a graphical tool for simple Individual Aircraft Tracking

HELICOPTER LOAD & USAGE MONITORING

The helicopter fleets of the Royal Netherlands Air Force (RNLAF) have 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 loads and usage monitoring programmes for these helicopter types.

PROUD

This flexible, operator-oriented fatigue damage prognostics tool has been developed by the NLR to estimate the severity of future usage scenario's. This tool is particularly useful to plan and predict the logistics 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 in-service fatigue cracks in the primary airframe structure of a helicopter. 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-area operations, the required maintenance actions can then be deferred (or not) to a more suitable moment and location.

AIDA

AIDA is a multi-channel retrofit data-acquisition system that the NLR has developed for the Lynx helicopter to measure and process the main rotor speed, the engine rpm's in various modules, the radar altitude and the sponson strain and torsion. Since its fleet wide introduction in the Lynx fleet of the Royal Netherlands Navy (RNLN), AIDA has been the basis for the fatigue life extensions of the mainframe, the sponson and the engine modules. AIDA has generated proven maintenance credits and has served as a very useful FLM tool to bridge the operational gap between the phasing-out of the Lynx and the introduction of the NH90 in the RNLN.

Force Life Management

NLR's role in supporting the operator with
- operational availability
- flight safety
- economy
- maintenance

INTEGRATED DATA MANAGEMENT
HELIUM and RAVIOLI

HELIUM is a secure database at NLR, containing all relevant helicopter flight and loads/usage data generated by RNLAF helicopters, covering Chinook, Apache, Cougar and the NH90. All data from all sorts of data sources can be handled (FDR, HUMS, flight admin data etc.). HELIUM 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 converting to and from XML documents, well defined syntax using XML Schemas, excellent support in e.g. Java, and a human readable format. RAVIOLI can be seen as the GUI on top of HELIUM. RAVIOLI (**R**eporting, **A**nalysis **VI**sualisation **O**f aircraft **L**ifecycle **I**nformation) can be defined as an *'IT-facility' for the military operator with an innovative, fully integrated toolbox for the analysis of usage, loads and maintenance data in a web-based application of acquisition, processing, storage, visualisation and reporting of data.*

NH90 HISDES

The maritime helicopter NH90 has recently entered service in The Netherlands. The positive results of Chinook and Apache Force Life Management experiences in The Netherlands led to a joint approach to develop a common flexible secure and integrated (multi-operator) Supportability Data Exchange system for the NH90 community, called HISDES (Helicopter Integrated Supportability Data Exchange System). HISDES will support the weapon system manager on different levels:
(1) occurrence and incidents reporting,
(2) RAM data establishment and analysis and
(3) Load & usage monitoring for structural integrity purposes.

PROGNOSTICS
PROUD

PROUD is an innovative tool for the military operator to estimate the severity of projected Chinook usage scenario's in terms of airframe fatigue. It is powerful in that any possible future Chinook mission profile can be generated in detail, including specification of internal or external loads. The user specifies the aircraft weight, the detailed mission type descriptions and associated mission mix. PROUD then calculates the severity of that assumed usage scenario, relative to a specific reference usage, which typically is the standard Dutch peace-time usage. In this way the operator can project the logistics footprint and estimate the type and level of airframe degradation for future out-of-area deployments.

PLATO

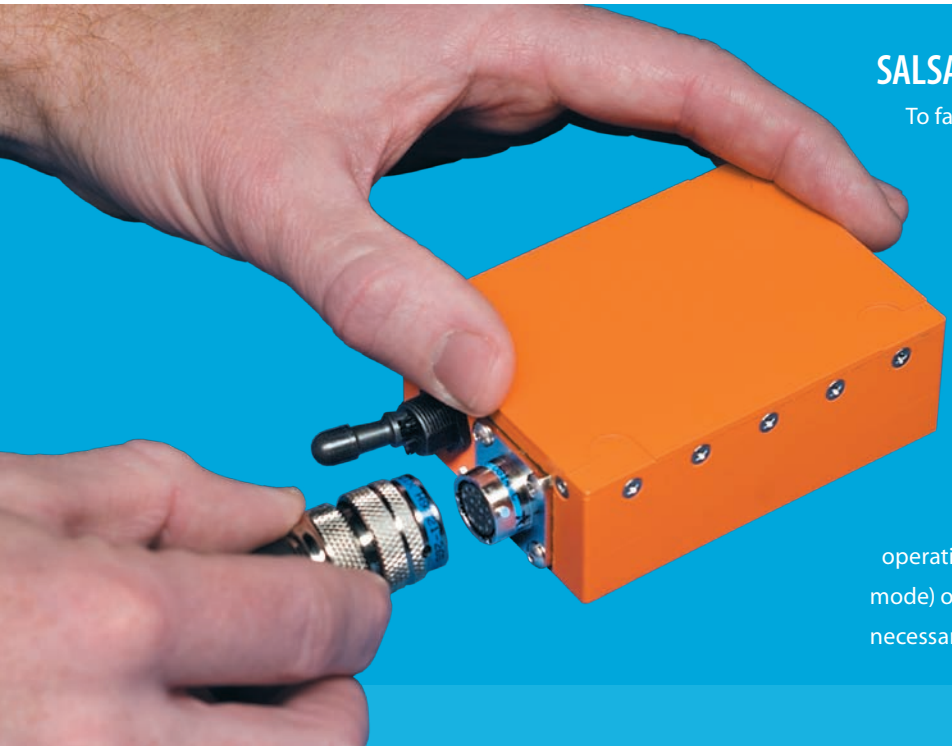
Using a graphical tool to present a fixed wing aircraft mission, in detail, it becomes possible for the operator to calculate the fatigue damage severity of any imaginary mission profile. The input for PLATO (mission profile PLAnning TOol) is a graphical representation of a mission. Per flight segment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

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 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 profile etc.) and linking this to measured flight loads and usage data, it becomes possible to calculate damage per flight segment or mission event.
FRR is the basic tool for structural integrity tools such as PROUD and HISDES.

TRANSPORT AIRCRAFT
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 airframe. The NLR has developed a loads and usage monitoring system dubbed HOLMES (Hercules Operational Life Monitoring & Evaluation System) that brings together measured flight data and flight administrative data from various sources. The collected information is used to compute the expended fatigue life of the critical areas of the airframe. The RNLAF now employs this system as a tool to take informed decisions with regard to fleet life management.



SALSA

To facilitate the quick-look evaluation of operational loads, the NLR has developed a unique device called SALSA (**S**tand **AL**one **S**tructural data **A**cquisition system). It is a miniaturized, stand-alone and autonomous 1-channel data acquisition system to monitor 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 therefore very limited, allowing quick and affordable loads assessments. Due to the long operating time (50 hrs continuous; 300 hrs in 'stand-by' mode) only a minimum level of operator involvement is necessary.

Capabilities and Installations

In support of Force Life Management activities, NLR combines a wealth of knowledge, experience and technical capabilities, covering fields such as:

- Composite Structures Technology (e.g. Resin Transfer Moulding, Advanced Fibre Placement, Thermal Analysis)
- Prognostics & Health Management
- ICT (e.g. Knowledge Discovery, Data Mining)
- Testhouse capabilities for material characterization and component and full scale evaluation of static and fatigue strength
- NDI test facilities (e.g. reliability of NDI, evaluation of new NDI techniques, In-service inspections)
- Fractography & failure analysis
- Avionics and instrumentation department

February 2009
Design, editing, production:
NLR Multimedia Group

Photography:
page 3: © CAVDKM

WHAT IS NLR?

- The National Aerospace Laboratory (NLR) is the key center of expertise for aerospace technology in the Netherlands;
- NLR employs around 700 people, including 300 with a Master's degree and about 160 with a Bachelor's degree;
- NLR's facilities include wind tunnels (for testing aircraft produced by Airbus, Lockheed Martin and others), simulators (for testing the safety of new flight procedures, among other things), and laboratory aircraft;
- NLR's revenue adds up to €75 million, with contracts accounting for €55 million (2008);
- 75% of our contract work is directly or indirectly government-funded

Information

National Aerospace Laboratory NLR
Voorsterweg 31, 8316 PR Marknesse, The Netherlands
Aerospace Vehicles Division
Gas Turbines & Structural Integrity,
A.M. Vollebregt
Tel.: +31 (0)527 - 24 81 86
E-mail: vollebre@nlr.nl