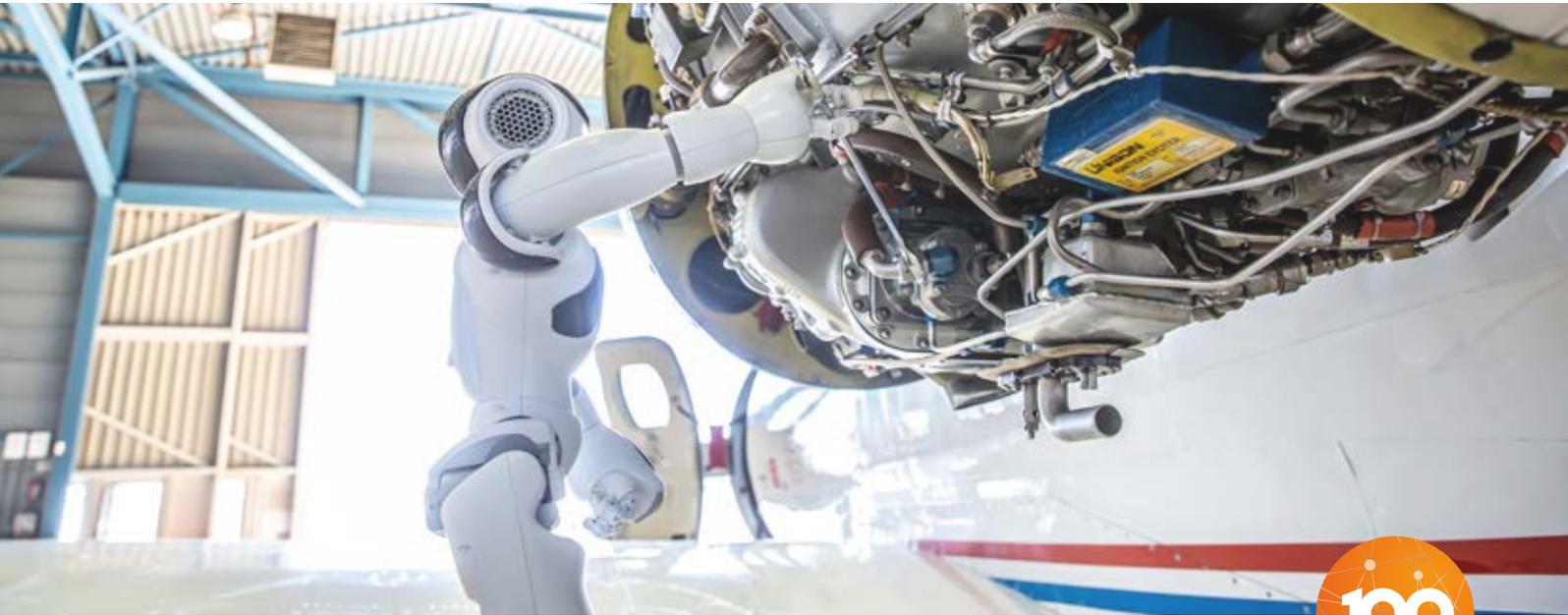




Dedicated to innovation in aerospace

Innovation in MRO



NLR - Royal Netherlands Aerospace Centre



Royal NLR

Innovation in MRO

If you are maintaining aircraft or if you are looking for innovative maintenance technologies to improve the availability of your aircraft or to reduce costs, NLR can support you. Or if you want to prepare for the future of aircraft MRO, we are your sparring partner.

Operators, maintenance organisations and OEMs aim for maximum aircraft availability at minimal costs. This objective drives, to a large extent, the value of aircraft maintenance. Achieving these goals requires expert knowledge and game-changing technologies. NLR offers practical solutions for excellence in maintenance operations and innovative maintenance technologies to improve availability and affordability for civil and military maintenance organizations, airlines and OEMs.

We have selected some of the projects, research and capabilities that we have developed ourselves and together with partners, for you to get to know more about NLR and our MRO activities.

We hope you enjoy reading and discovering more about NLR.

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Maintenance Management

NLR creates smarter organisations by providing managerial decision support tools and consultancy services for strategic challenges. We are capable of balancing business, economic and technological issues.

Maintenance Technology

NLR creates smarter technologies by developing innovative soft and hardware tools and solutions. We create new maintenance resources and capabilities. We employ cutting-edge knowledge and technologies to automate maintenance tasks and processes using robotics, prognostics and artificial intelligence.

MRO solutions by NLR

Maintenance Training

NLR creates smart training curriculums and training devices with state-of-the-art training concepts and technologies. We create training value using state-of-the-art training design principles and modern technologies such as virtual and augmented reality.

Maintenance Engineering

NLR creates smarter solutions by combining existing knowledge, techniques and methods. We optimise your maintenance operation, maintenance planning, and resources, spares and personnel allocation. We drive process and product improvements, for example with quantitative data analysis.

FlexPlan

Flight schedule driven maintenance planning

WHY?

Operators use various maintenance planning concepts, however, none of these concepts really takes the flight program into account. Common maintenance concepts such as block programs are easy to schedule, but take an aircraft out of service for some time. Equalized programs break up large inspections but they can introduce excessive access and preparation times. NLR has developed a maintenance planning concept that solves these issues.

WHAT?

Flexplan is an automated tool that automatically creates maintenance programs and helps you to optimise your maintenance planning. It offers you aircraft availability and reduces your time spent on maintenance programs and planning.

NLR's FlexPlan

- Reads a Maintenance Planning Document, interprets the applicability of individual tasks and creates an operator specific Aircraft Maintenance Program automatically
- Creates small packages of tasks, optimally clustered to minimise access and preparation times
- Assigns the packages to maintenance slots based on the flight schedule
- Updates the maintenance slots if last-minute changes in the flight schedule occur.

FlexPlan only uses readily available information, namely a Maintenance Planning Document, the aircraft maintenance status, the aircraft configuration, a flight schedule, and a list of maintenance facilities. We then use an automated workflow to dissect the Maintenance Planning Document, create packages, schedule these packages and update the schedule if required.

FlexPlan makes extensive use of Artificial Intelligence to optimise the packages, schedule these packages and update the schedule.

The result is a comprehensive maintenance program, with packages that minimise access and preparation times, that schedules maintenance around your flight schedule, and is sufficiently robust to facilitate last-minute changes to the maintenance schedule if your flight schedule is disrupted.

And the best thing is, it is all done automatically; you do not need to spend time on an operator specific Aircraft Maintenance Program or maintenance scheduling. It is all done for you. And since FlexPlan adheres to the task intervals specified by the original equipment manufacturer, you do not face regulatory issues.





ARVI

Autonomous Robot for Visual Inspections

WHY?

Aircraft technicians are scarce. And with the increasing worldwide aircraft fleet and aging of technicians, the situation is likely to get worse.

A solution could be to automate your visual inspections? As an alternative for your aircraft technicians, for example an autonomous system to perform time-consuming visual aircraft inspections.

WHAT?

NLR developed ARVI (Autonomous Robot for Visual Inspections), a clever robot system able to map inspection areas and identify defects such as dents, scratches, broken wires, arcing, corrosion, dirt, leakages and many more.

We use an autonomous vehicle to move the sensor system to the inspection areas, whether it is a zone or a system component. ARVI can navigate through the hangar and through aircraft just like human technicians. She avoids collisions and positions the sensor system autonomously.

ARVI has a modular design what makes it easy to configure the robot for specific areas. We may need different movement systems for work in fuel tanks and on top of the fuselage. Our modular approach means that these adaptations will have a minimal effect on the other modules

FD XAI

Failure diagnostics with eXplainable Artificial Intelligence (XAI)

WHY?

Would you like to know how your component or when system is going to fail, before it fails? This would help you with your troubleshooting, repair planning or to scope repairs to preventively remove a working component.

FD XAI not only identifies the failure modes, it also explains why a specific failure mode occurs (and not another failure mode). The explanation helps maintenance personnel understand the diagnosis, and troubleshoot failures on the line and in the shop.

WHAT?

NLR developed a new tool to diagnose failures using Artificial Intelligence. It is a clever piece of software that looks at the failure modes of previous repairs and the aircraft usage. We use Artificial Intelligence to determine the relation between aircraft and system usage and the actual failure modes of repaired parts. We can use these relationships to diagnose components or systems and identify the failure modes.

Failure diagnoses using eXplainable Artificial Intelligence can be performed before a part actually fails. This means that it is a useful tool to determine the failure mode of parts removed in serviceable condition based on predictive indicators. It helps the shops to repair these parts and it reduces no-fault-found.

The trust in the results of computerized diagnoses is highly dependent on the transparency of the analyses. To make the outcomes of failure diagnoses acceptable for maintenance personnel, the algorithms use eXplainable Artificial Intelligence.







AARE

Aircraft availability and resource estimator

WHY?

Maintaining aircraft means balancing budgets and resources to achieve the best aircraft availability. This balancing act is complicated by uncertainty; maintenance is inherently unpredictable.

WHAT?

AARE or aircraft availability and resource estimator offers a management decision support tool to determine the impact of changes to budgets and resources on the fleet availability (and vice versa) based on realistic reliability data, and it is specifically tailored to cope with uncertainty. It provides the user with valuable insights into the relation between fleet availability, resources and budget. It supports you with your financial planning, and set realistic availability targets, such as your On Time Performance.

AARE serves different purposes. It can help you with your financial and operational planning in an existing operation. However, you can also use it if your operations change or if you prepare for fleet changes, such as the introduction of a new aircraft type. It also offers an interesting learning experience for managers and management trainees. AARE can be tailored to your needs.





Project customers:

Royal Netherlands Air Force (RNLAf)
Defence Equipment Organisation (DMO)

Research organisations: NLR

Netherlands Organisation for Applied Scientific Research (TNO)

Start: February 2000

Duration: ongoing

F-35 Acquisition & Operational Readiness Preparation

WHY?

NLR helped the Royal Netherlands Airforce (RNLAf) with the F-35 acquisition and operational readiness by focussing on transforming the Defence Equipment Organisation (DMO) into a smart buyer and by assisting the Air Force with a smooth transition from F-16 to F-35. Within this programme, multiple training & education projects have been carried out to design and improve training for pilots, maintenance staff, and mission support crew.

HOW?

Several training methods, tools and activities conducted by NLR throughout the F-35 programme include:

- Training Needs Analysis for pilot maintenance staff, and mission-support roles
- Design of a F-35 Pilot Competency Profile, initial and recurrent training course content
- Training Media Selection Analysis
- Business case for a Maintainer Training Centre (MTC)

WHAT?

The activities mentioned helped develop a variety of products and services, including:

- Initial and recurrent training course content for pilots and maintenance staff
- Design and execution of an Operational Test & Evaluation plan for Continuation Training
- Design and construction of a WLT (Weapons Loader Trainer) including Augmented Reality applications.





Project partners:

Royal Dutch Airlines (KLM)

Research organisation: NLR

Start: June 2016

End: 2019

Augmented reality for maintenance training

WHY?

KLM expressed the need for more innovative training media to modernise and improve maintenance training.

HOW?

To ensure well integrated use of training media, the project started with a review of the current training design and analysis of current training content. Subsequently, there was a study of whether Augmented Reality (AR) could add value for the aircraft systems that are difficult to train through traditional classroom training. Requirements for the AR application and training design were defined before starting actual development. Finally the prototype was evaluated through an experiment.

The project is performed in a highly interactive and agile way. Bi-weekly sprints were held with experts from relevant areas such as maintenance experts, application developers, human machine

interface experts and educational experts, which ensured accuracy and acceptance of intermediate and final results.

WHAT?

The result of the project is a modernised, problem-based training design for maintenance training that enhances understanding of the systems and system interaction. This design comprises less traditional instruction and more trainee activity via paper-based assignments and problem-based AR scenarios.

The experiments proved that trainees score better using AR when it is fully integrated in the training design; trainees retained more of what they learned, had deeper understanding and retention time was longer compared to the traditional classroom training. Important lessons learned are the importance of shared AR and a maximum of 20 minutes wearing the AR goggles.



Competency based maintenance training

WHY?

The development of the European Military Aviation Regulations (EMAR) resulted in changes in the Dutch military aviation regulations. The content and levels of the maintenance type training for the F-16, AH-64D, CH-47D/F and the NH-90NFH therefore needed to be updated. Besides, the training did not fully meet the needs of the (novice) maintenance mechanic and the training did not always represent the actual work of mechanic accurately. The focus of the training was merely on theory. Practice was not offered in an integrated manner.

HOW?

In cooperation with maintenance mechanics and instructors, the different steps in an instructional design process have been carried out. To analyse the training needs, several workshops were held with both experienced and inexperienced maintenance mechanics. Throughout the process, different presentations and discussions were held to explain and define the desired training concept.

Working sessions with the instructors and developers were subsequently held, in order to develop a training in accordance with this concept.

WHAT?

First, a competency based training concept was defined in line with the 4 components instructional design principles (4C/ID). This concept focuses on whole task training. Theory and part task practice are integrated to support the whole task scenario. Based on the outcome of the training needs analysis, qualification profiles were defined. Finally the training, including supporting materials, was developed. Besides training materials, an assessment method also was developed, allowing student coaching and evaluation. This method comprises competencies including their observable behaviours and can be used for continuous coaching and assessment.



Project partners:

Royal Netherlands Air Force:
Royal Military Air Force School (KMSL)

Research organisation: NLR

Start: May 2014

Duration: 3 years

Additive Manufacturing for Royal Netherlands Air Force

NLR has more than 50 years of experience of metals which is incredibly important for additive manufacturing research, together with knowledge of aircraft certification. With the increased understanding of the printing process and subsequent reproducibility, applications using metal printed parts in aircraft components are becoming feasible from an economic point of view are now much closer. Of course, you can print the same thing twelve times in one print job, then test eleven of them and put the twelfth in the aircraft. But that obviously makes the twelfth component far too expensive. You want to be able to print such a component in large numbers, be able to detect production faults, and know for certain that approved components can be fitted in the aircraft.

First for the Royal Netherlands Air Force

The first printed product in the Netherlands by metal additive manufacturing that actually flew on a helicopter at year-end 2016 was a ladder mount for the NH90 helicopter of the Royal Netherlands Air Force.





It is a coupling that is affixed to the helicopter and to which a ladder can be mounted so as to perform maintenance. Although hardly a critical part from an operational point of view, it was a good case to start with. It showed how it could be useful for an organisation like the air force. Metal additive manufacturing also raises an important logistics-critical question for the air force, namely whether on a mission you can print parts locally instead of taking them with you or having them sent out.

The 3D-printed ladder bracket is 40% lighter but stronger and more durable than the original design. 3D printing enables the Royal Netherlands Air Force to have parts produced faster, reduce maintenance costs, and at the end improve the deployability of her weapon systems. The Royal Netherlands Air Force commissioned the development of the ladder bracket. The project was a collaborative venture, with Fokker Aerostructures responsible for engineering, NLR-Netherlands Aerospace Centre for 3D printing and testing, BPO-Delft for redesign and the Defence Materiel Organisation for certification.

DEMETER: Improve the technology readiness level of promising structural health monitoring systems

WHY?

Many (aircraft) structures have multiple load paths where after a (partial) failure of a load path the remaining structure can carry the limit load without catastrophic failure until the structure is repaired, replaced or modified. The structural integrity of an aircraft is sustained by means of repeated (costly) inspections. Application of a reliable SHM system for multiple load path structures therefore is an interesting application area to reduce the cost of ownership and to improve the system operational availability. This would prevent periodic (costly) inspections and allows maintenance on demand after the system signals a (partial) failure. Especially in hard to inspect areas this could yield a significant maintenance cost saving. Examples are: the wing or tail structure consisting of multiple spars and a lower and upper skin that often can sustain a broken spar, the vertical stabilizer and wing attach fittings, a wing carry through bulkhead or engine mounts.

HOW?

Within DEMETER SHM technologies based on optical fiber Bragg grating (FBG) sensors were developed for multiple load path structural components. An FBG is a small segment in an optical fiber that causes a shift in wavelength due to stretching or compressing of the fiber which can be correlated with a strain value.

FBGs have a number of appealing advantages for application in (aircraft) structures, such as light weight, many sensors in one fiber, tolerant for harsh environments (temperature, chemical components), long term stability and durable, completely passive and no interference with other signals. The optical fibers can be embedded in the (composite) structure or surface mounted.



WHAT?

First, a competency based training concept was defined in line with the 4 components instructional design principles (4C/ID). This concept focuses on whole task training. Theory and part task practice are integrated to support the whole task scenario. Based on the outcome of the training needs analysis, qualification profiles were defined. Finally the training, including supporting materials, was developed. Besides training materials, an assessment method also was developed, allowing student coaching and evaluation. This method comprises competencies including their observable behaviours and can be used for continuous coaching and assessment.

Project partners:

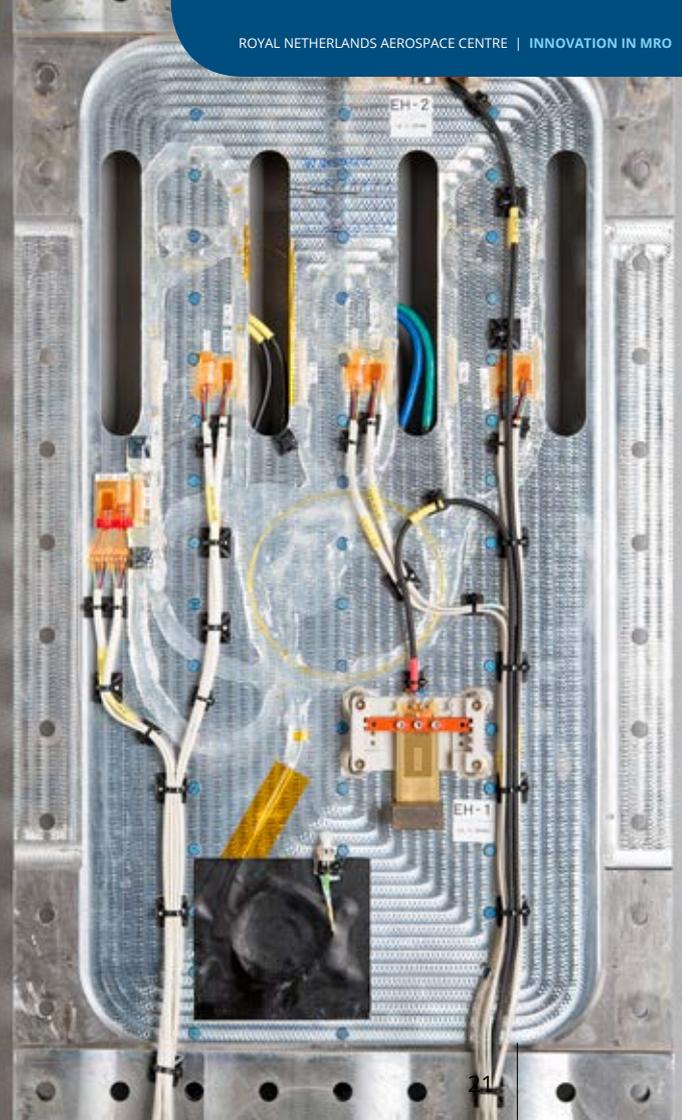
Industry (EU): Airbus (DE)

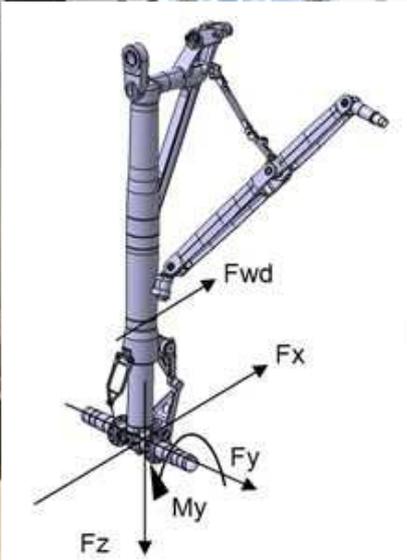
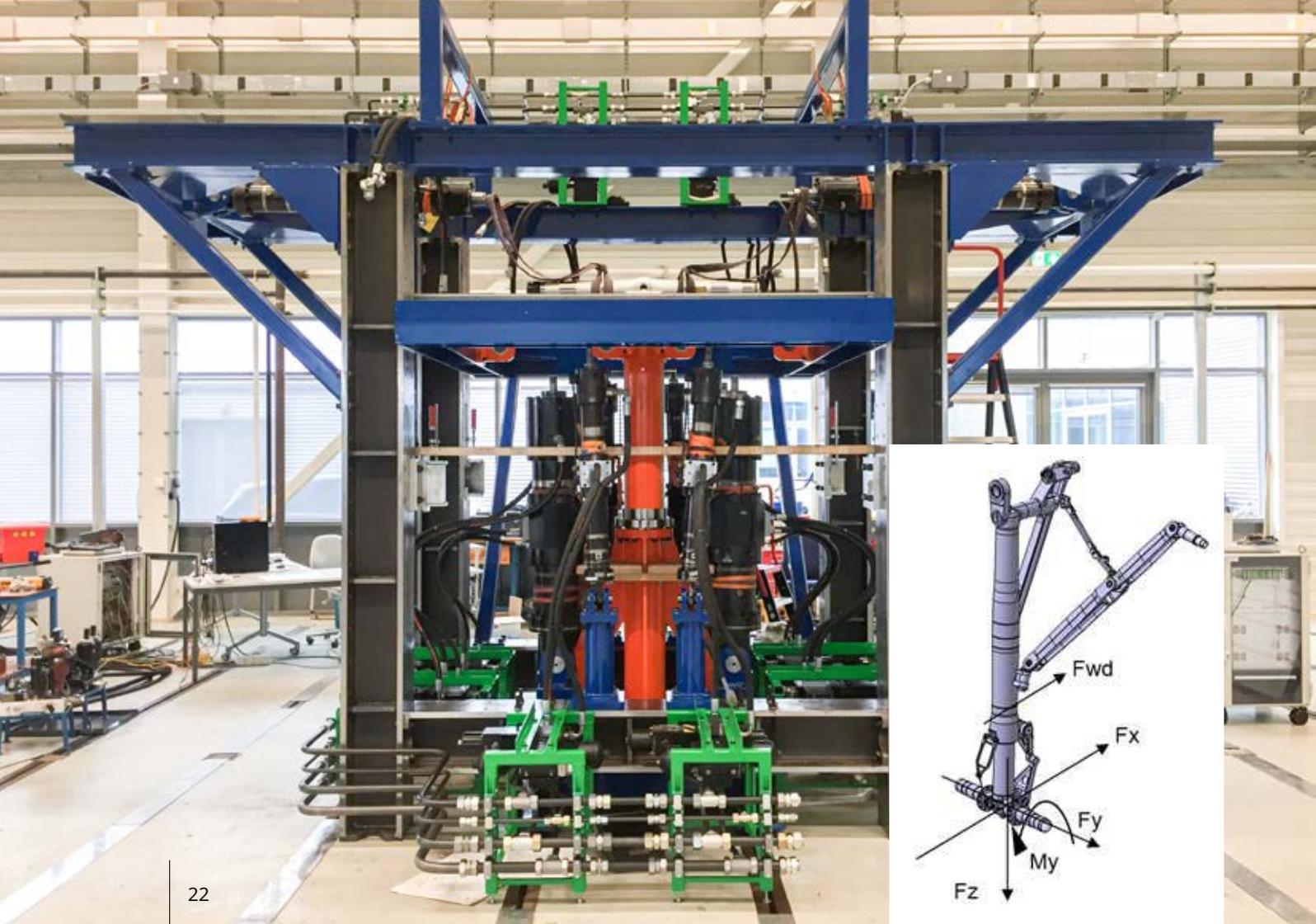
Research organisations:

German Aerospace Centre (DLR), NLR

Start: December 2015

Duration: 4 years





ALGesMo: Advanced Landing Gear Sensing and Monitoring

WHY?

Landing gears are designed according to the Safe-Life philosophy yielding a fixed number of load cycles. The true loads on landing gears during operation are not measured and the gear is replaced when it reaches the design life, irrespective of the remaining life. By measuring the loads on the landing gears the usage life can be improved. Apart from this, various other important quantities can be measured such as: accurate detection of hard landings, aircraft weight and balance measurements, sensitive air-ground transition detection, braking torque control and others.

HOW?

Several systems have been tried in the past to measure the loads on a landing gear. These all failed for one reason or another. A new very promising approach is to measure the loads with the use of optical fibre Bragg grating (FBG) sensors, which offer several advantages over traditional sensors, such as low weight, no EMI, no recalibration and robust for harsh environments.

WHAT?

In the project a complete monitoring system is being developed and tested on ground. The monitoring system consists of a (retrofit) sensor system for the landing gears, an optical fibre processing unit that can be mounted in the electronics bay of civil aircraft to measure the response of the optical fibre sensors based on state-of-the-art photonic integrated chips, the routing and harness of the optical connection between the sensor system and optical fibre processing unit. The whole system will be thoroughly tested in a dedicated test rig to determine its performance under limit load conditions and endurance testing at elevated temperatures.

Project partners

Industry (NL): Technobis Fibre Technologies BV

Industry (EU): Airbus (UK), MEGGITT (UK and CH)

Research organisation: NLR

Start: September 2016

Duration: 4 years



1INTEGRATE: an integrated Structural Health Monitoring system for stationary and rotating aircraft components, based on fibre optic sensing

WHY?

The sustainment costs of military aircraft make up a substantial part of the total life cycle costs. An important world-wide trend in this respect is the transition from corrective and preventative maintenance to predictive maintenance, which is expected to lead to large cost savings and availability improvements. For predictive maintenance it is essential that the actual system condition can be measured. Much research effort is currently being put in the development of technologies that enable predictive maintenance, among which Structural Health Monitoring (SHM). However, the transition of these technologies into service is very slow. One reason for this is the lack of standardization and the poor integration of the new technologies with existing data acquisition systems.

HOW?

The project partners aim to integrate three key data acquisition technologies into one comprehensive Structural Health Monitoring system for stationary and rotating aircraft components, based on fibre optic sensing: an existing modular data acquisition unit, a patented contactless power and data transfer module and a miniaturized fibre

optic interrogator based on ASPIC technology (application specific photonic integrated circuits). The loads and damage data collected with the SHM system will be fully synchronized with data from other sources, such as flight and usage parameters. The fibre optic sensors in the form of Fibre Bragg Gratings (FBG) that are incorporated in the SHM system will offer many significant advantages over conventional strain gauges.

WHAT?

The SHM system will enable loads & usage monitoring to be performed much more efficiently in comparison with currently available technology. Moreover, it will combine functionalities that could not be combined before, viz. simultaneous loads monitoring, mechanical impact event detection and damage detection/localization, both in stationary and in rotating aircraft components. The following examples serve to show the relevance and potential use of the developed SHM technology

- Loads monitoring of landing gears (hard landings, remaining useful life)
- SHM of medium-sized and large UAVs
- Enhanced rotor balancing of helicopters

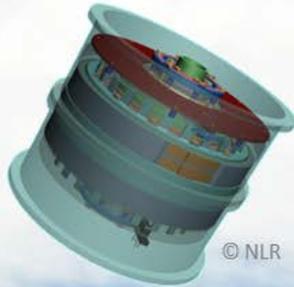
Project partners:

Industry: Technobis Fibre Technologies, ACQ International, Curtiss-Wright Avionics & Electronics

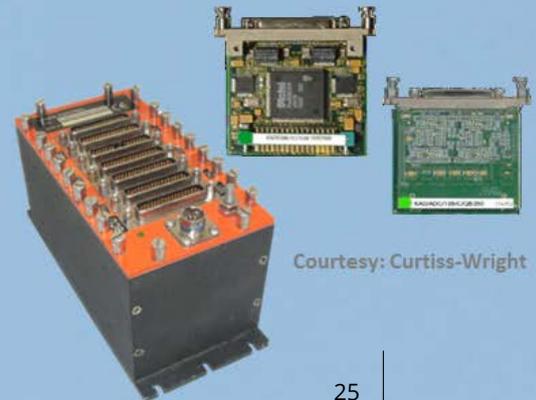
Research organisation: NLR

Start: October 2017

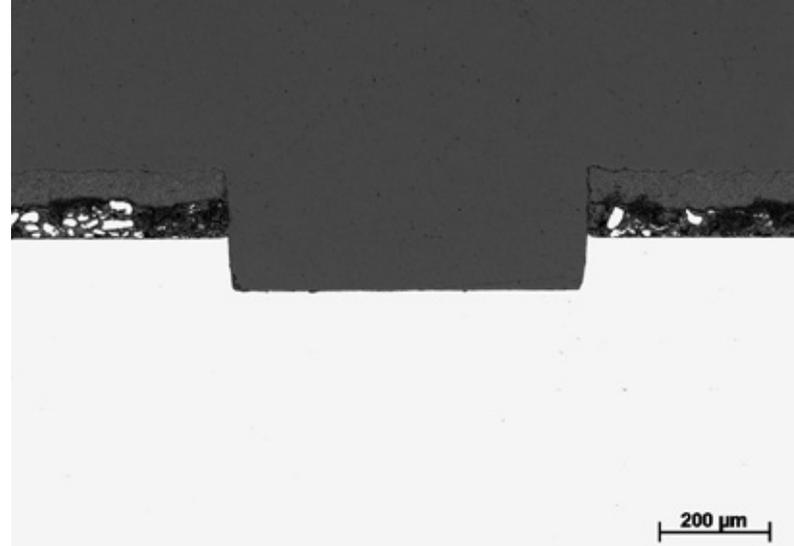
Duration: 3 years



Courtesy: Technobis



Courtesy: Curtiss-Wright



Development of chromate free primer technology

WHY?

For decades, RNLAf has relied on the robust corrosion inhibition by use of pre-treatments and primers containing hexavalent chromium. However, the downside to the use of Cr6+ is its toxicity to humans and the environment. As a result, the use of Cr6+ is restricted increasingly by legislation such as REACH (Registration, Evaluation, Authorisation and restriction of Chemicals). The research into chromate free products is ongoing for years and this research contributes to developing alternative products for corrosion prevention.

HOW?

The project is divided into two phases. During the first phase, the chromate free inhibition technologies in their current development stage are benchmarked with existing chromate containing and chromate free primers. The screening consists of testing for the properties adhesion (dry and wet), corrosion resistance (in various forms), and flexibility. The latter property is of importance especially for fighter aircraft, which undergo significant deflections under certain loading conditions. The goal of the benchmark testing is to determine performance in comparison with existing products and determine areas in which improvement of the lithium and magnesium technology is desired.

There to, paint systems known to have good properties were selected as positive references for comparison. In the second phase, the improved primers will be tested again to determine the degree of improvement.

WHAT?

The main R&D activities of the project are:

- Development of magnesium rich primer: magnesium particles serve as sacrificial anode to the underlying substrate, which is more noble than magnesium)
- Development of lithium inhibitor technology: Similarly to chromates, the lithium salts leaches out of the primer upon damaging of the coating. The lithium salts form a protective layer on the (aluminium) substrate

Project partners

Industry: Akzo Nobel Aerospace Coatings

Research organisations (NL): NLR

Defence Material Organisation

Start: January 2017

Duration: 2 years



Engineering Failure Analysis

Do you need to know the root cause of why your component, structure or plant failed? What causes your decrease in production yield? Or to know whether your component or structure sustained damage during operations that exceeded the operational limits? Do you need a second opinion, an independent expert, a report on failure analysis or recommendations to prevent failure in the future?

NLR's Test House is specialized in material research and engineering failure analysis on complex components. We have over 60 years of experience in aerospace, defense and high tech industry that strive for the highest safety standards with extensive knowledge on failure modes of materials with a specialization in:

- structural materials
- high temperature materials (Ni-, Co- and Ti-alloys)
- composites

Equipment for mechanical testing, materials analysis and fractography, which enable full analysis capabilities, including: dynamic and static test machines, optical- and scanning electron microscopes (SEM), energy dispersive analysis of X-rays in the SEM (EDX, for analysis of the chemical composition) and non-destructive testing.

From a multi-disciplinary approach NLR delivers the essential feedback to design, manufacturing, maintenance/repair and safe operation.



NLR offers material and failure analysis for the aerospace and high tech industry. From a multi-disciplinary approach NLR delivers the essential feedback to design, manufacturing, maintenance/repair and safe operation. The modern material facilities and extensive experience provide NLR the capabilities to ensure proper material solutions for our national and international customers.



Royal NLR in brief

 One-stop-shop	 Global player with Dutch roots	>100 100 years young	 Amsterdam, Marknesse, Schiphol
 Innovative, engaged and practical	 For industry and government	 For civil and defence	 632 employees
 € 73 M revenue	 75% Dutch, 21% EU and 4% international	 Active in 29 countries	 Extremely high client satisfaction

About NLR

Royal Netherlands Aerospace Centre

NLR is a leading international research centre for aerospace. Its mission is to make air transport safer, more efficient, more effective and more sustainable. Bolstered by its multidisciplinary expertise and unrivalled research facilities, NLR provides innovative and comprehensive solutions to the complex challenges of the aerospace sector.

NLR's activities span the full spectrum of Research, Development, Testing & Evaluation (RDT & E). Given NLR's specialist knowledge and state-of-the-art facilities, companies turn to NLR for validation, verification, qualification, simulation and evaluation. They also turn to NLR because of its deep engagement with the challenges facing our clients. In this way, NLR bridges the gap between research and practical applications, while working for both government and industry at home and abroad.

Royal NLR stands for practical and innovative solutions, technical expertise and a long-term design vision, regarding their fixed wing aircraft, helicopter, drones and space exploration projects. This allows NLR's cutting-edge technology to find its way also into successful aerospace programmes of OEMs like Airbus, Boeing and Embraer.



Dedicated to innovation in aerospace

100 YEARS



Milestones

1919 Establishment NLR	1921 First air brakes	1923 Flutter research	1926 First Dutch helicopter	1955 New propulsion helicopter	1962 Flight data stored digitally	1966 Supercritical wing profiles	1970 New wing shapes	1980 Accurate position determination	1982 Safer & quieter flying	1983 First astronomical satellite	1987 Vegetation monitoring Africa	1987 Air Traffic Control Simulator	2001 Lynx service life extension	2006 Detect-and-avoid- system	2006 Fighter pilots training simulations	2009 Hover trial simulation	2011 Antimatter detector cooling	2012 Tiltrotor wind tunnel model	2016 Cleaner, quieter landing	2019 NLR 100 years!
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A century of knowledge and innovation in aerospace

Wanting to progress is human nature. We dream about the unknown. We're curious about what we may find beyond the horizon and want to get to the bottom of things we don't understand. NLR has been an ambitious, knowledge-based organization for a hundred years now, with a deep-seated desire to keep innovating. We are very proud that we have received the royal predicate and that we are now the **Royal Netherlands Aerospace Centre**. Our knowledge and expertise have made us one of the driving forces in the aerospace sector, both in our own country and abroad. Our staff search tirelessly for new technology and have the courage to think outside the box, translating trends and developments into actual solutions for the market. That drive is helping us make the world of transport safer, greener, more efficient and more effective.

Above all, we keep looking ahead – because we have to keep setting ourselves tougher challenges if aerospace is to become more sustainable in the long term. How can we make sure that the environmental impact is minimized? How can we guarantee aviation safety despite its exponential growth? In short, how can we use airspace more efficiently? How can we make the best possible use of satellites and satellite data? The future looks highly demanding yet fascinating and it will require even faster innovation and closer cooperation, with the right driving forces behind it. We are devoting our knowledge and expertise to that future, with an eye on the interests of the commercial sector, the general public and the environment at all times.

Together with our partners, we can help shape the fascinating world of tomorrow. We are on the threshold of innovations that will really break the mould. But plans and ideas only really get moving if they are nourished with the right kind of energy – and the amazing thing is that the source of that energy is still exactly the same as it was when we started a hundred years ago. That driving force is NLR's knowledge.

Knowledge powers the future

NLR research aircraft 1919 - now



Hybrid electric propulsion
(HEP) study model

Cessna 550 Citation II

Pipistrel
Electric plane



**Fairchild Swearingen
SA226-TC Metro II**



Queen Air



Hawker Hunter T.7



Fokker S.14.1 Machtrainer



Fokker F.VIIa PH-NLL



Fokker F.II PH-RSL

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