Accelerating the future of aerospace

R&D for Safety and Human Performance

AEROSPACE OPERATIONS SAFETY AND HUMAN PERFORMANCE

The Royal Netherlands Aerospace Centre (NLR) is an ambitious organisation that focuses on innovation in the aerospace industry. We assist aviation companies, air traffic control, airports, regulatory bodies and governmental authorities by translating trends and developments into solutions. Our cutting-edge research and unique facilities ensure that NLR stays abreast of new developments and innovations in an ever-changing industry.

This booklet gives an overview of our expertise in the fields of safety and human performance, plus some of the projects that we have been working on in recent years in operational safety, organisational performance, human-machine interaction and human performance. Discover more about our research, facilities and services.

Henk van Dijk
Vice President Aerospace Operations Division

OPERATIONAL SAFETY

In the operational safety field, NLR carries out research and gives advice on the safety of changes in the industry and the introduction of new concepts, operations and technology.

Performing risk analyses gives customers an understanding of the risks and potential hazards that are identified. We are also involved in aeronautical studies (analysing safety at airports) and collision avoidance studies (analysing the division of the available airspace, e.g. with the increasing use of drones).

Finally, NLR is involved in new certification methodologies in operations and organisations to enhance the safety of aviation in the future.

Operational Resilience

THE CHALLENGE

Highly optimised aerospace systems are inherently vulnerable to disruptions like extreme weather, cyber incidents or cascading failures. These disruptions can spread rapidly, turning localised issues into system-wide crises. Recent developments, such as the EU Critical Entities Resilience Directive, underscore the growing importance of resilience as a strategic priority for critical infrastructure, including aviation. Resilience demands more than recovery. It requires proactive preparedness and the ability to adapt dynamically to unforeseen events.

HOW WE CAN SUPPORT YOU

Our approach combines systemic analysis, simulation, and training to address a wide spectrum of resilience challenges. We provide tailored solutions that align with the operational needs of aerospace organisations:

- **Risk, vulnerability & resilience assessment**
  Using our decades of safety expertise, we identify critical vulnerabilities and design mitigation measures. This includes advising on how to structure resilience frameworks, define key performance indicators, and how to embed resilience into your organisation's culture. Our assessments also include oversight methods to monitor resilience levels, ensuring compliance and continuous improvement.
- **Simulation-based stress testing and training**
  Resilience must be tested under realistic conditions. That is why use a phased approach, starting with strategic tabletop exercises, where teams explore decision-making and coordination in controlled scenarios. These scenarios can be further developed into advanced simulations using our state-of-art facilities, where systems are stress-tested under extreme conditions (e.g., winter operations in our ATC simulator). This allows us to uncover operational gaps, validate response strategies, and refine procedures.
- **Human-centric resilience**
  Humans are crucial in emergency response situations. NLR's expertise in stress management, fatigue mitigation, and adaptive training ensures teams are equipped to perform under pressure. We focus on enhancing decision-making in uncertain circumstances, communication protocols, and sustained performance, helping crews maintain resilience during prolonged or unexpected events.


STOP

THE SOLUTION

The new hazard scenarios informed the safety assessment process, helping to identify and manage potential risks posed by new systems, configurations, or aircraft entrants. Specific analyses such as FMECA and FTA were used to complement the approach.

We used the latest European climate forecasts to pinpoint potential effects and predicted climate changes. The research also considered new concepts for future aircraft, air traffic control (ATC), and airport operations. We identified relevant hazards through expert assessment and applied them to generic airports and locations. Ultimately, we determined the risk levels and implemented mitigating measures to address them.

ALBATROS

Advanced systems and solutions for better practices against hazards in the aviation system

As one of the most progressive sectors in transportation, air travel is under pressure to become more environmentally efficient. The ALBATROS initiative is a large-scale collaboration between major European aviation stakeholders, aiming to demonstrate how recent technical and operational R&D achievements can help transform the aviation industry into a more sustainable sector.

THE CHALLENGE

Within the project, NLR explored the emerging hazards in aviation and the impact of climate change on airports in Europe. The main focus was on:

- evaluating the risk posed by new hazards in aviation and the introduction of new aircraft through a combination of modelling, expert insight, and safety data analyses.
- identifying the potential impact of climate change on flight safety and operations at airports.

WHAT WE DID

A novel risk assessment method was developed, using a scenario-based approach to determine the risk related to new hazards. Additionally, a tailored methodology was designed to analyse safety data for each identified scenario.

Regarding climate change, a location-specific and airport-type-specific risk profile was created to assess the impact of climate change on European airports. This involved using a risk matrix to map out all possible combinations of probability and occurrence of climatological changes to key meteorological variables.

PARTNERS

View all partners on:
albatros-horizon.eu

DURATION

2023 - 2025

FUNDING

Horizon Europe
GA. no. 101077071

Integral safety analysis

PARTNERS
Dutch Ministry of Infrastructure and Water Management, Royal NLR

DURATION
2024

The Dutch government has stated that an Integral Safety Analysis needs to be performed when new decisions about noise pollution lead to significant changes in air traffic. These decisions can have a significant impact on the development of air traffic at Amsterdam Airport Schiphol. The potential consequences of the decisions were therefore analysed.

THE CHALLENGE

The goal of the research project was to conduct an independent analysis of the impact of new noise pollution measures on overall performance and other relevant policy parameters, including external safety, noise, and emissions near Amsterdam Airport Schiphol, and to identify where safety might be compromised.

WHAT WE DID

In the 2024 Integral Safety Analysis, an analysis was made of whether measures aiming at limiting noise pollution have a detrimental effect on the overall safety of Amsterdam Airport Schiphol (both flight safety and external safety). NLR determined which ICAO accident categories are relevant and how the new measures affect the fatality risk. Furthermore, the impact on third party risk with respect to the accident probability, accident location and accident consequence was investigated.

THE SOLUTION

NLR analysed the impact of new policies on ICAO accident categories and examined how autonomous safety improvements influenced airport safety. The research culminated in an advisory report that provided insights into the effects of new policies on safety at Amsterdam Airport Schiphol.

THE SOLUTION

In depth knowledge of airport-related regulations, safety and risk management, safety data analysis and operational procedures enable a helicopter view of all the factors that build a safe airport operation.

Airport safety studies

A major area of expertise within the AOSH department is performing safety studies for airports. When there are changes in operations at an airport, a safety case is performed to analyse the impact of the new operation on safety at the airport and the associated risks are analysed.

PARTNERS

Amsterdam Airport Schiphol, Dutch Air Traffic Control (LVNL), Royal NLR

DURATION

2023 -2026

THE CHALLENGE

The goal is to keep the operation of the airport safe. This can only be achieved by assessment of operational and infrastructural changes, data analysis for pro-active safety, assuring compliance with regulations and by installing a healthy safety management system. NLR supports all these areas.

WHAT WE DID/WHAT WE ARE DOING

Examples of safety cases by NLR:

- Research into the possibility of adjusting the airspace structure so that the probability of Traffic Alert and Collision Avoidance System (TCAS) Resolution Advisories (RA) between Visual Flight Rules traffic (VFR) under the Terminal Manoeuvering Area (TMA) and Instrument Flight Rules traffic (IFR) in the TMA is minimised.
- Considering the ATC-related safety risks of using runway 18L in low visibility at Schiphol Airport.
- Analysis of the risk of runway crossings by aircraft, tow and vehicles at those locations during periods that the runway can be used for take-off or landing at Schiphol Airport.
- Workshops with airport, ground handlers, operators and ATC, to arrive at a shared understanding of the major risks of a change.
- ICAO Annex 14 compliance: transverse slope non-conformity and mitigating measures.
- Research into the braking performance of aircraft on contaminated runways.
- Determination of safety hotspots based on the analysis of a year of ground radar data.
- Cost benefit analysis: determination of the effectiveness of Runway Status Lights to reduce the risk of runway incursions.


SPEED
V/S -1000
B/S
NAV
LOC
CAT 1
AP 1
1 FD 2
A/THR
220
200
180
160
QNH 1013

HUMAN- MACHINE INTERACTION

The main driver of successful human-machine interaction is how the interaction between the operator and technology is shaped. To that end, NLR conducts research into automation within the aviation industry, for example with remote towers and single-pilot operations. Key areas of research are the impact of advanced automation on HMI design, effective task division between automation and operator, and adaptive automation.

THE SOLUTION

A safety risk assessment was performed to analyse potential failure cases and characterise their potential impact on flight operations, while evaluating key mitigations at the level of flight crew working practices, operational procedures, and training. This assessment also provides relevant quantitative and qualitative input for future impact assessment exercises related to the development of eMCOs and subsequent SiPO regulatory measures. This includes an estimation of the operational benefits and cost elements associated with the introduction of eMCO and SiPO, taking into account various aircraft operators and air operations.

eMCO-SiPO

extended Minimum Crew Operations-Single Pilot Operations

Ongoing developments in technology, automation and autonomous unmanned aircraft pave the way towards operating Commercial Air Transport (CAT) with reduced flight crews in large aeroplanes. Hence there is an interest to explore the options. Research is conducted into whether extended Minimum-Crew Operations (eMCO) and Single-Pilot Operations (SiPO) affect safety as compared to Multi-Crew Operations.

THE CHALLENGE

The two main objectives of this research project were to assess the feasibility:

- the implementation of eMCO in the EU regulatory framework by developing a reference risk-assessment framework and investigating a series of key safety hazards and mitigations
- the implementation of SiPO in the EU regulatory framework through a preliminary analysis of the related main safety hazards.

WHAT WE DID

The feasibility of eMCO-SiPO was considered from both safety and efficiency perspectives. Within this context, NLR examined the impact of fatigue, sleep inertia, boredom, and physiological needs on safety during nominal and non-nominal flights, with a particular focus on the transition from Multi-Crew to eMCO or SiPO operations.

PARTNERS

EASA, ADSE, Deep Blue, DLR, Ries Simons Consulting, Royal NLR

DURATION

2022 - 2025

JARVIS

Just A Rather Very Intelligent System

PARTNERS

Amsterdam Airport Schiphol, Dutch Air Traffic Control (LVNL), Royal NLR

DURATION

2023 -2026

FUNDING

SESAR 3 Joint Undertaking GA. no. 101114692

Digitalisation presents possible solutions to the challenges that arise due to the ever-increasing complexity in the aviation ecosystem while simultaneously raising challenges that need to be addressed. For example, with increased air traffic due to autonomous and human operated aircraft, what will help to make safe and efficient Air Traffic Management possible within this new ecosystem? Applying the digitalisation trend means that new solutions to these kinds of problems can arise in the form of digital support.

THE CHALLENGE

The three key challenges addressed in JARVIS are:
Data availability – addresses how to manage the distributed data within the environment.
Digital assistance – addresses how to design digital agents that assist humans in comfortable, transparent, and simplified ways.
Digital multi-agent system – addresses how to assure safety and performance in AI-based decision making.

WHAT WE ARE DOING

Within the JARVIS project, NLR focusses on two main tasks:

- Creating a safety framework for the development of a digital assistance in the cockpit, in order to support the digital assistant designers in creating a safe cockpit tool.
- Develop guidelines for the design of human-AI teaming. These guidelines will among others be used for human-AI interfaces in the cockpit, at ATC and at airports.

THE SOLUTION

JARVIS will design and validate three AI-based ATM solutions to support pilots, ATC operators and airport operators in non-safety and safety critical operations:

- An airborne digital assistant to support pilots.
- An ATC digital assistant to support ATC operators in different tasks.
- An airport digital assistant to support airport operators in several operative, safety tasks.

HUMAN PERFORMANCE

In the field of human performance, NLR carries out research into the aspects of human performance that have the highest impact on safety and explores the potential of new sensors and algorithms to objectively measure aspects of human performance. The main drivers in this research are fatigue, workload and situational awareness. Research is conducted by doing experiments, e.g. by measuring brain activity or pupil size to give an indication of the workload. This is how NLR research helps enhance the working conditions of among others Air Traffic Controllers.

THE SOLUTION

Data collection on a representative sample of 216 volunteer ATCOs at six ATSPs showed that 5.6% of duties were associated with a critical level of fatigue. The factors contributing most to these critical fatigue levels are night shifts, challenging weather conditions, monotonous traffic situations and extended working hours without breaks. To decrease the critical fatigue level further, improvements to the rostering process, enhanced fatigue data collection/monitoring mechanisms and practical operational measures for preventing ATCO fatigue should be considered.

ATCO Fatigue

Air Traffic Controllers (ATCOs) face numerous fatigue-related challenges due to irregular working hours and demanding workloads. In response to the European regulations aimed at preventing ATCO fatigue and stress, a scientific evaluation funded by the European Union Aviation Safety Agency (EASA) was undertaken by a consortium of NLR and Welbees.

THE CHALLENGE

The three objectives of the research:

1. To assess the implementation of EU regulations on ATCO fatigue by Air Traffic Service Providers (ATSPs) in the EU.
2. To conduct research into the prevalence, causes and effects of ATCO fatigue to provide guidance and assess the need for possible further development of the related EU rules and practices.
3. To assess the potential impact of future technologies on the ATCO workload and fatigue.

WHAT WE DID

Research was conducted into the prevalence, causes and effects of ATCO fatigue in actual operations. This research included analysing exposure to fatigue in a sample of actual rosters from a representative sample of 16 Air Traffic Service Providers (ATSPs) in the EU. Both subjective and objective data on ATCOs' fatigue, sleep and workload was collected from ATCOs of six ATSPs. The aim was to validate the subjective fatigue ratings used in the subjective data collection campaign, to analyse the effects of fatigue on ATCO performance and to determine the feasibility for ATSPs of using objective measurement techniques to measure fatigue in real time during ATC operations.

PARTNERS

EASA, CAAi, Ecorys, MovingDot, Ries Simons Consulting, Royal NLR, Welbees

DURATION

2022 - 2024

CODA

Controller Adaptive Digital Assistant

The Digital European Sky vision anticipates a complex future ATM environment with new airspace vehicles flying at varying speeds and altitudes, increasing the need to reduce ATM infrastructure costs while simultaneously enhancing performance. AI is expected to provide the capacity to address challenges caused by increased air traffic complexity. However, the expanding use of AI in ATM poses a risk of inadequate man-machine integration, potentially leading to efficiency loss or accidents.

THE CHALLENGE

The major objective of the CODA project is to increase the efficiency, capacity, and safety of ATM, by optimising human–AI teaming. To this end, the aim is to demonstrate the possibility of developing a system in which tasks are performed collaboratively by hybrid human-machine teams and dynamically allocated through adaptive automation principles.

WHAT WE ARE DOING

Prior to development of the AI application itself, it is important to establish the level of automation that is applicable nowadays in ATC, to describe how automation is applied in the operation (i.e. in a number of use cases) and to offer a perspective on the future role of the ATCO, and in particular how this role may be influenced by higher levels of adaptive AI. Within CODA, NLR is therefore focusing on conducting research into the definition of the ATCO future role.

PARTNERS

View all partners on:
sesar.eu/projects/coda

DURATION

2023 - 2026

FUNDING

SESAR 3 Joint Undertaking
GA. no. 101114765

THE SOLUTION

During the project, the following outcomes will be generated:

- an ATCO future tasks prediction model
- an ATCO future mental conditions prediction model
- a current ATCO mental state monitoring tool
- a human–AI teaming quality/level assessment tool
- an adaptive automation strategy
- a prototype of the CODA system capable of simulating specific scenarios in real time

THE SOLUTION

They key findings of the study were that:

- The current FTL limits are largely effective in managing fatigue risk.
- Duty duration was found to be a consistent predictor of (high) fatigue, alongside start time, prior sleep quantity, and time awake.
- Crew category and individual factors, such as age and gender, also influenced fatigue levels.
- Controlled rest (CR) is an effective tool for managing fatigue, particularly during critical phases of flight.

FTL 2.0

Flight Time Limitations Effectiveness Study

To maintain safety during flight operations, flight time limitation (FTL) requirements have been set to prevent crew fatigue. The FTL2.0 research study reviewed the effectiveness of the provisions related to flight and duty time limitations and rest requirements set out in Annexes II and III of the Commission.

THE CHALLENGE

The research included an assessment of the impact on aircrew alertness of the following aircrew duty periods:

- Duties of more than 13 hours at the most favourable time of the day.
- Duties of more than 11 hours for crew members in an unknown state of acclimatisation .
- Duties including a high level of sectors (more than 6).
- On-call duties such as standby or reserve followed by flight duties, with a specific focus on 'other than airport standby'.

The study also examined the impact of controlled rest during flight duties and the conditions under which flight crew make use of it.

WHAT WE DID

NLR managed and largely executed the data collection campaign. A mixed-methods approach was used to gather insights from aircrew members, combining surveys, interviews, and data analysis. The real-world data collection involved over 220 flight and cabin crew members across eight airlines. These participants provided valuable data regarding their levels of alertness, fatigue, and sleep during actual duties. The results and recommendations were shared with EASA and the main EU stakeholders (unions, NAAs, airlines etc.).

PARTNERS

EASA, DLR, Finish Institute of Occupational Health (FIOH), Jeppesen Stockholm University, Royal NLR

DURATION

2022 - 2024

ORGANISATIONAL PERFORMANCE

An effective safety management system needs a healthy safety culture. Therefore NLR conducts research into organisational cultures and how changes in the organisation affect that culture. NLR also assists with the development and documentation of procedures and helps authorities with ways to increase the efficiency of oversight. A major topic in organisational cultures is the Safety Management System (SMS), which is a mandatory tool for organisations that allows them to manage safety in a structured way. Safety performance monitoring, risk management and change management are the main elements of the SMS. NLR assists in safety analyses domestically and in operational processes to enhance the organisational performance of companies in the aviation industry.

PARTNERS

Civil Aviation Authority Singapore (CAAS), Royal NLR

DURATION

2020 - 2024

Civil Aviation Authority Singapore-safety culture

The Singapore Aviation Safety Culture Framework was developed in early 2023, providing a safety culture framework specifically adapted for the Singapore aviation sector. This provides the sector with a shared basis for communication and improvement of the safety culture. The framework is consistent with ICAO publications on safety culture and contains both existing and new insights into safety culture.

THE CHALLENGE

What is innovative about the Singapore Aviation Safety Culture Framework is that it contains four sociocultural factors that indicate which sociocultural factors in Singapore need to be taken into account so that actions to improve the safety culture will be most effective.

WHAT WE DID

The following four milestones were developed during the project:

- Developing a Singapore Aviation Safety Culture Framework
- Developing and conducting a Safety Culture Survey
- Organising focus group meetings with leading organisations in the Singapore aviation sector
- Developing and publishing a Safety Culture Handbook

SINGAPORE AVIATION SAFETY CULTURE FRAMEWORK

SOCIO-CULTURAL FACTORS

HIERARCHY | COHESION | CONTROL | ACHIEVEMENT

THE SOLUTION

The Singapore Aviation Safety Culture Framework was used as the basis for the Singapore Aviation Safety Culture Survey, which was sent to all 400+ organisations within the Singapore aviation sector. The target group included, amongst others, airlines, ANSPs, ground handling services, maintenance organisations, aviation training organisations, and CAAS Safety Regulation Officers. The survey's findings were presented at the Singapore Aviation Forum.

17 focus group meetings were held with key Singapore aviation organisations to gather insights from management and operational staff, and foster a positive safety culture amongst all staff.

THE SOLUTION

Building further on the FALCO project, IFAV3 will deliver detailed ready-to-use procedures about operations, training, rating maintenance and deployment. ATCO endorsement strategies will be further investigated and detailed to supplement all remaining aspects needed to reach a TRL 6 complete maturity.

Furthermore, the know-how about flexible ATCO endorsements from SESAR2020 will be transferred to RTCs.

IFAV3

Increased Flexibility of ATCO Validations 3

In current operations, airspace is organised in sectors and an ATCO is responsible for handling the traffic within an allocated sector. These sectors have their own specificities in terms of shape, available routes, traffic patterns, and entry and exit procedures to surrounding sectors. ATCOs are trained to work in one specific sector. Increasing the number of sectors an ATCO is endorsed to work for, increases flexibility, cost efficiency of ATC and ATCO productivity. This will hold for Remote Tower Centres (RTCs), operating multiple airports with a flexible controller deployment, as well.

THE CHALLENGE

The major aim of IFAV3 is to simplify the process of acquiring and maintaining ratings for air traffic controllers to allow more flexible deployment of controllers within the control sectors of an Air Traffic Services Unit (ATSU). Furthermore, it will be investigated if the developed IFAV methods and ideas can be applied for a Remote Tower Centre (RTC).

WHAT WE ARE DOING

Within IFAV3, NLR investigates how training for the Area Control Centre (ACC) and RTC can be standardised, so that an ATCO can work in multiple sectors and towers, while maintaining the current level of safety. The successful and promising flexible endorsement strategies will be developed to TRL6 complete maturity and validated accordingly

PARTNERS

View all partners on:
sesarju.eu/projects/IFAV3

DURATION

2023 - 2026

FUNDING

SESAR 3 Joint Undertaking
GA. no. 101114683

About NLR

Royal Netherlands Aerospace Centre

POLICY SUPPORT

INDUSTRIAL DEVELOPMENT

APPLIED RESEARCH

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 also find its way into successful aerospace programmes of OEMs like Airbus, Boeing and Embraer.

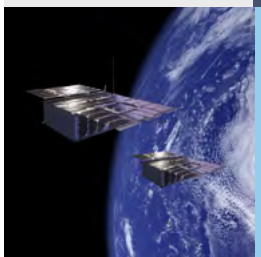
NLR in brief

AMSTERDAM, MARKNESSE, ROTTERDAM, BRUSSELS

1000+
STAFF

144M
TURNOVER

78% DUTCH, 17% EU & 5% WORLDWIDE



SINCE
1919

FOR INDUSTRY, GOVERNMENT, CIVIL, DEFENCE AND SPACE

GLOBAL PLAYER WITH DUTCH ROOTS ACTIVE IN 24 COUNTRIES

VERY HIGH CUSTOMER SATISFACTION

Netherlands Aerospace Centre

NLR AEROSPACE OPERATIONS SAFETY AND HUMAN PERFORMANCE:

NLR supports innovation in safety and human performance to ensure effective, efficient and safe operations.

- Airport safety studies
- Safety management studies
- Safety case and Risk assessments
- Human factors evaluation and measurements

FOR MORE INFORMATION:

Michel Piers

Business manager

+31 88 511 34 39

michel.piers@nlr.nl

sesar JOINT UNDERTAKING

Co-funded by the European Union

NLR Amsterdam

Anthony Fokkerweg 2

1059 CM Amsterdam

+31 88 511 3113

info@nlr.nl

www.nlr.org

NLR Marknesse

Voorsterweg 31

8316 PR Marknesse

+31 88 511 4444

info@nlr.nl

www.nlr.org

E2037-02 - April 2026