# STRATEGIC RESEARCH & INNOVATION AGENDA

2017 UPDATE | VOLUME 1

ACARE

Advisory Council for Aviation Research
and Innovation in Europe

# DELIVERING EUROPE'S VISION FOR AVIATION

## Strategic Research and Innovation Agenda – 2017 update
## Volume 1

- Serving society's needs
- Maintaining global leadership

Advisory Council for Aviation Research and Innovation in Europe

# FOREWORD

Aviation is recognised as one of the top advanced technology sectors in Europe and generates innovation that benefits society at large far beyond its direct operational sphere. It provides close to twelve million skilled jobs, directly and indirectly, and contributes over 700 billion euros to Europe's gross domestic product. Home to some 400 airlines and nearly 700 airports, European aviation plays a key role in serving society's needs for safe, secure and sustainable mobility in Europe and all over the world. Its impact on the wider European economy is significant and must be sustained.

European demand for air transport is anticipated to grow continuously until 2050 and beyond. Sustainable mobility is required to satisfy this growth and it is essential that travel remains safe, secure, fast, affordable and environmentally friendly. Industrial competition is fierce, not only from established world regions but also from new, strong challengers. In this context, there is more to be done in the regulatory field within and outside Europe to ensure a global level playing field in the sector.

In 2011 a European group of personalities set out a vision of European aviation with the publication of Flightpath 2050. In response to this, ACARE produced a Strategic Research and Innovation Agenda (SRIA) in 2012 that defined the path to reach these ambitious goals. Since then there have been many changes and developments that affect aviation directly and indirectly, and these justify the release of this new version which is updated and adapted to meet the new challenges.

We invite all public and private stakeholders in European aviation to consider the revised priorities set out in this document in their future research and innovation programmes.

**Prof Rolf Henke**
*Board Member for Aeronautics, DLR*
*Chair ACARE*

"Aviation sets the pace of a global community. The need for fast and safe transport, combined with challenging eco-environmental requirements, has advanced the European aviation sector towards world-leading technology in many fields. Representing all European stakeholders in aviation, ACARE has developed a roadmap towards the best system performance with minimum negative effects. Achieving these ambitious goals will require extensive research with long-term commitment. Only a combination of profound expertise, fresh insights and courage can yield the innovations we seek."

**René de Groot**
*Managing Director & COO KLM*
*Vice-Chair ACARE*

"Aviation makes a substantial contribution to our economies, connecting markets and people worldwide. Key and well considered policies and incentives will ensure that European air transport remains safe, clean and secure. Innovation is needed to be and remain competitive and deliver high quality services to the customers."

**Michel Wachenheim**
*Policy Adviser to CEO, Airbus*
*Vice-Chair ACARE*

"European aviation has a world lead in the manufacturing and services industry which is facing new challenges and ever increasing competition. Innovation will help preserve European capability, jobs and our valuable market share."

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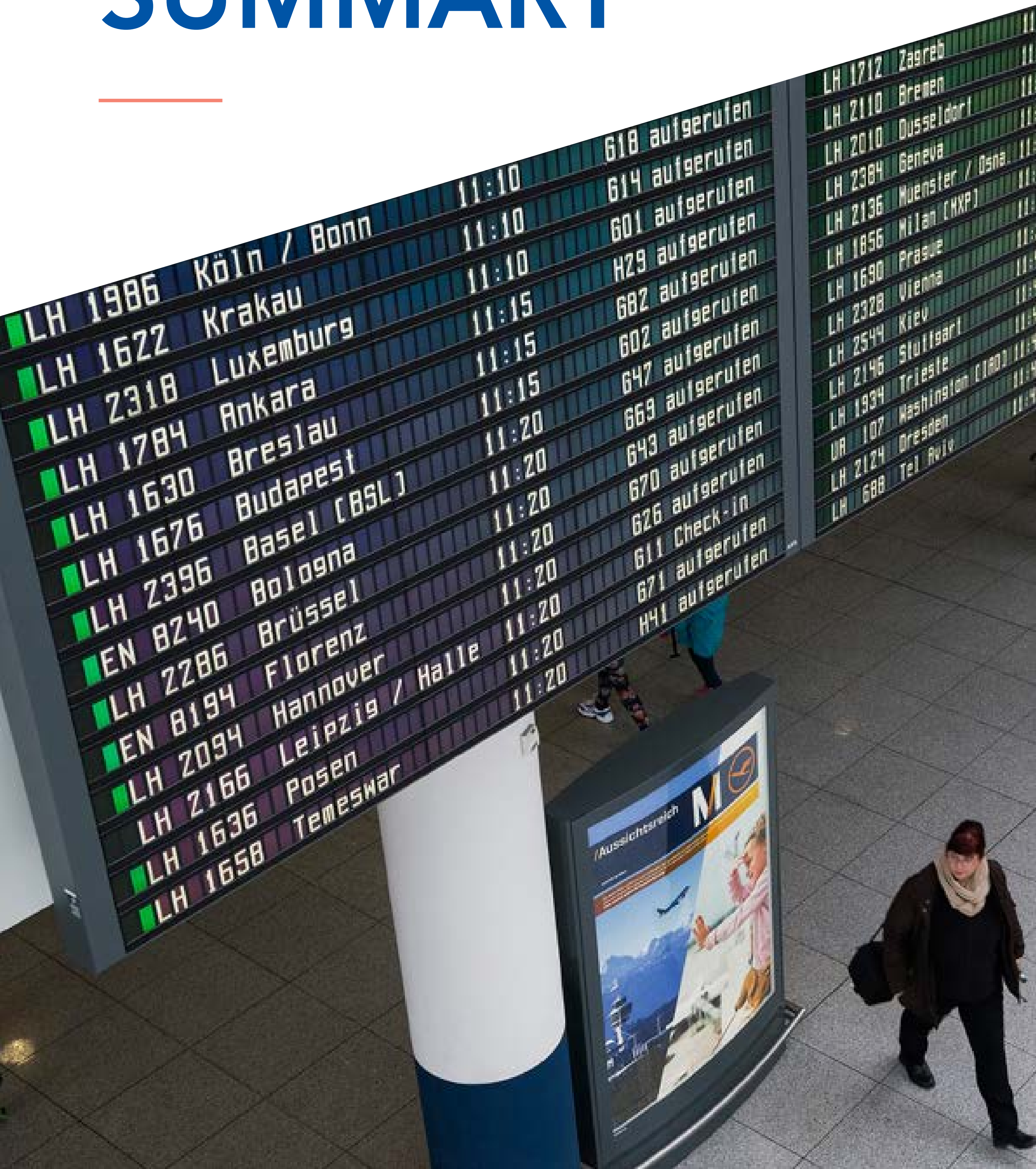
# EXECUTIVE SUMMARY



# EXECUTIVE SUMMARY

## Aviation: innovation for the benefit of society

**ACARE has developed a strategic research and innovation agenda (SRIA) to meet the challenging goals set by Flightpath 2050. Research and innovation in aviation is the key to tomorrow's mobility and prosperity as well as environmental and energy challenges.**

A customer-centric, integrated European transport system underpinned by common standards, innovative business models and smooth processes is essential for seamless, door-to-door journeys. Mobilising the diverse intellectual potential, resources and organisations within Europe is vital in developing the future state. Prioritising this advanced technology sector is critical to maintaining European competitiveness with developments in aviation frequently leading to spill-over applications in other sectors. Research and innovation excellence must be stimulated at the right time, which is now.

Commercial aviation has come a long way since the dawn of the jet age. Growth is anticipated to continue, particularly in developing economies, but also elsewhere: to improve connectivity for business and leisure, for visiting friends and relatives, and for high-value freight. It contributes to the geographical integration of Europe, hence supporting its economic and political integration. It is a unique industry which has a strong sense of working together across the globe, with common language, standards and practices.

In recent decades the sector has demonstrated significant achievements in the transport arena, with major improvements in safety and security and impressive reductions in environmental impact, in particular emissions and noise. Advances directly benefit commercial aviation but improvements are also clear for other airspace users, search and rescue, emergency and public safety applications as well as the recreational market. This covers a diverse range of aircraft types including general aviation and rotorcraft.

Passenger numbers are expected to double in the next 20 years. Current aviation ground infrastructure will not be able to accommodate the coming traffic volumes. The demand for service to regional and urban areas has increased with the liberalisation of the European marketplace. A greater number of vehicle movements will require further developments in safety and security. Remotely-piloted aircraft systems (RPAS) need to be integrated in the overall system. This means that tomorrow the sector will have a whole new set of requirements to fulfil. In this context, research and innovation is expected to lead to disruptive technologies across many fields including aircraft configurations, engines, equipment and systems, materials, alternative energies, infrastructure, electronics, digitalisation and IT systems as well as human-machine interfaces to name a few. Sustainable development is key.

In summary, the sector will need to develop solutions to support the Flightpath 2050 goals in order to satisfy mobility needs of European citizens in a sustainable manner, to strengthen the economy and to ensure that 'the industry lead in this advanced technology sector is maintained'.

# A DYNAMIC STRATEGIC RESEARCH AND INNOVATION AGENDA

The ambitious goals of Flightpath 2050 remain valid to deliver two aims: firstly to serve society's needs for safe, more efficient and environmentally friendly air transport; and secondly, to maintain global leadership for Europe in this sector with a competitive supply chain and competitive operators. The roadmap to achieve these goals can be met by addressing the following key challenges:

- **Challenge 1:** Meeting societal and market needs
- **Challenge 2:** Maintaining and extending industrial leadership
- **Challenge 3:** Protecting the environment and the energy supply
- **Challenge 4:** Ensuring safety and security
- **Challenge 5:** Prioritising research, testing capability and education.

Since 2012 a number of external factors and boundary conditions have changed, and together with other developments have prompted ACARE to update the SRIA. Examples of these trigger factors are:

- Repercussions of events such as MH370, MH17, Germanwings 9525 where they may affect research and innovation or policy
- Cybersecurity threats, e.g. to aircraft equipment or ATM systems
- Developments in digitalisation and big data
- Future stringency in emissions standards for $CO_2$ and ultra-fine particles
- Increased importance of noise annoyance and health impacts
- New mobility system concepts, stakeholders, business models and vehicle types including RPAS (remotely-piloted aircraft systems)
- Increased competitiveness challenges for European air transport stakeholders
- New technologies, materials, manufacturing processes and system concepts vital for the European aviation sector
- Emerging hazardous substances legislation affecting certified aviation processes and products
- Availability of appropriate research and test infrastructure
- Availability of a capable work force

Furthermore, research undertaken since the first edition of the SRIA by European, national and regional programmes, both private and public, needs to be considered.

Innovation in aviation is complex, capital-intensive and takes time. Typically, fifteen years can elapse from the generation of a new idea to technology being fully developed for application on the next generation of air vehicles. A shift to more customer-centric and lower-carbon operations has to be achieved. Specific challenges arise from stringent certification requirements consistent with the paramount importance of safety in the sector. This requires many changes, including new operational concepts, alternative fuels fit for the future and so on. Infrastructure development is dependent on the availability of excellent research, testing and validation capabilities. Furthermore future aircraft and systems will require a paradigm shift in methodologies for certification and testing, platform integration and full-scale demonstration.

## International cooperation

It is vital that new developments take into account the international nature of commercial aviation. This document contains many references to the importance of globally aligning policies, standards and practices to ensure seamless introduction of new technology and trouble-free operations.

Globalisation presents many opportunities for the European aviation sector. However, this requires a level playing field so that all parts of the industry can compete fairly with the rest of the world, whether established organisations or new entrants that may benefit from specific support.

ACARE activities include the development of comprehensive and up-to-date strategies to manage international co-operation. This has identified key partners, as well as the potential for new alliances with selected third countries.

## Fostering implementation

ACARE has developed a comprehensive roadmap to deliver the Flightpath 2050 goals, and as part of this it will continue to foster the need to monitor achievements and progress on the SRIA objectives.

As an example, in 2015 the ACARE working group on energy and environment estimated that we had secured an overall 38% reduction in $CO_2$ per passenger kilometre against a goal of 50% reduction goal for 2020. Similarly, technical solutions showed a potential reduction of 37% in perceived noise has been achieved against a goal of 50%, also by 2020. Whilst this represents significant progress, effort must be further strengthened to meet the even more challenging goals for $CO_2$, noise and NOx emissions set for 2050.

Part of ACARE's brief is to monitor progress towards Flightpath 2050 goals, and a number of steps have been taken to do this. It is essential to have continued support from the EC, Clean Sky, SESAR Joint Undertaking, Coordination and Support Activities and other organisations to ensure a picture that is complete and up-to-date, and to enable identification of further gaps in research to be addressed. New generations of aircraft under development integrate many technologies that contribute very significantly to the ACARE goals: new aerodynamics, weight savings, new engines, computing capacity, air traffic management and operational benefits, and so on. Monitoring of progress in implementation is ongoing, and in the mid-term will continue to focus on technological developments, including RPAS (remotely-piloted aircraft systems), as well as broader collaboration with European Technology Platforms and other key organisations.

## Supporting the needs of Europe and its member states

ACARE is working actively to promote inclusivity across European, national and regional levels. This can only be done taking into account differing socio-political and sustainability considerations, and needs to be supported by a comprehensive policy framework designed to enhance synergies and exploit complementarities.

ACARE provides a platform for dialogue between industry, research establishments, academia and other aviation stakeholders, member states and regions together with the European Commission with its various bodies (JU, JTI etc.). It is essential to harmonise and promote research, technology and innovation thereby facilitating cooperation and collaboration. New trends must be detected and managed with strategic positioning and dissemination. The dialogue extends outward to other modes of transport and to research in different fields such as the digital economy and energy.

Recommendations and outcomes from this platform have been taken up by the different challenges and are incorporated throughout the SRIA. Future activities will continue to ensure a joined-up perspective that embraces all players for the benefit of European aviation.

The development of effective and efficient aviation policy and regulatory frameworks within Europe is necessary to address, in particular, governance, funding and financing issues. This is a prerequisite for delivering the Flightpath 2050 vision.

The precise timing for implementation of innovative solutions into new air vehicles, operations and services will be driven by the willingness of society to accept the change, the capacity of the market to afford the change and the capability of innovators to deliver it.

The previous SRIA document detailed a roadmap phased over three timescales: short-term (2020), medium-term (2035) and long-term (2050). This document develops this dynamic to present action areas covering these timescales and maintaining the overall objective to deliver the Flightpath 2050 goals.

The following sections provide a brief overview of the five challenges in which research must be conducted. The main SRIA document follows the Executive Summary and comprises Volume 1 which contains the full text with comprehensive descriptions of each of the action areas. Volume 2, which will have more specific details on research and innovation areas, will be published separately.

# CHALLENGE 1
## Meeting societal and market needs

Meeting societal and market needs is about true journey-wide customer-centric mobility for both passengers and freight.

This means that passengers, freight forwarders and shippers must be the clear focus of the transport sector in which aviation is a key player. This requires a paradigm shift from the current perspective, centred on the service provider, to one in which the customer comes first.

This must cover all segments of the door-to-door journey providing the highest possible level of performance and predictability. Core values in an advanced and innovative transport environment are collaboration, co-operation and data sharing giving customers access to reliable, timely and unbiased information. Society requires seamless connection across the different transport modes that make up a door-to-door journey.

The demand for both business and leisure travel continues to increase. At the same time, society and customers require mobility to be efficient and sustainable. In addition, air transport is expected to further support economic growth.

All these aspects must be facilitated by the design and implementation of a resilient, sustainable and customer-centric intermodal transport system that meets European mobility goals and regulatory demands.

The three key areas of Challenge 1 are: design of a customer-centric intermodal transport system; travel process management; and integrated air transport. These lead to the action areas for Challenge 1.

### Action areas for Challenge 1

1.1 Understand customer, market and societal expectations and opportunities

1.2 Design and implement an integrated, intermodal transport system

1.3 Develop capabilities to evaluate mobility concepts, infrastructure and performance

1.4 Provide travel management tools for informed mobility choices

1.5 Deliver mobility intelligence: journey information, data and communication

1.6 Provide tools for system and journey resilience, for disruption avoidance and management

1.7 Evolve airports into integrated, efficient and sustainable air transport interface nodes

1.8 Design and implement an integrated information, communication, navigation and surveillance platform

1.9 Develop future air traffic management concepts and services for airspace users

1.10 Address cross-cutting issues: system intelligence, human factors and automation support, autonomy and resilience

### Flightpath 2050 goals for Challenge 1

1. European citizens are able to make informed mobility choices.
2. 90% of travellers within Europe are able to complete their journey, door-to- door within 4 hours.
3. A coherent ground infrastructure is developed.
4. Flights arrive within 1 minute of the planned arrival time.
5. An air traffic management system is in place that provides a range of services to handle at least 25 million flights a year of all types of vehicle.

# CHALLENGE 2

## Maintaining and extending industrial leadership

The global aviation market is increasing in size and Europe must work to maintain its industrial competitiveness. Competition is increasing and now comes not only from established players but also from emerging challengers that receive national support. Substantial investment is required in innovation, research and technology with the appropriate, strong, positive supporting policies.

New business models are changing the ways in which new developments are funded. Costs of entry to the sector are reduced with greater use of digital and data-based business models. There are many opportunities for Europe to exploit its capabilities globally, also by building strong alliances with emerging partners. With regard to human resources, Europe must attract and retain the best talent for world-class innovation, research and technology development.

Leadership in innovation is a major competitive differentiator, notably in domains of energy and environmental performance. The market demands ever-shorter cycles for technology integration with, at the same time, aggressive pricing. Supporting policies must be developed to include emerging cross-sectorial enablers such as digitalisation, big data and new industrial paradigms.

The level of support and investment must match the aspirations of the aviation sector as a global leader, and ensure that it continues to generate a vast positive contribution to the European economy. The mechanisms for this support must build on best current practice, target the full innovation value chain, and recognise the unique lead times of technology maturation, and the scale and complexity of future technologies. All must be done in the context of a level global playing field.

### Action areas for Challenge 2

2.1 Increase competitiveness in product industrialisation

2.2 Develop high-value manufacturing technologies

2.3 Embed design-for-excellence in the product lifecycle

2.4 Secure continued and focused investment

2.5 Exploit the potential of operations and maintenance, repair and overhaul (MRO)

2.6 Develop innovative and optimised testing

2.7 Establish new business/enterprise models and initiatives

2.8 Lead the development of standards

2.9 Streamline certification

### Flightpath 2050 goals for Challenge 2

1. The whole European aviation industry is strongly competitive, delivers the best products and services worldwide and has a share of more than 40% of its global market.

2. Europe will maintain leading-edge design, manufacturing and system integration capabilities and jobs supported by high profile, strategic, flagship projects and programmes which cover the whole innovation process from basic research to full-scale demonstrators.

3. Streamlined systems engineering, design, manufacturing, certification and upgrade processes have addressed complexity and significantly decreased development costs (including a 50% reduction in the cost of certification). A leading new generation of standards is created.

# CHALLENGE 3
## Protecting the environment and the energy supply

Environmental protection is, and will continue to be, a key driver for aviation. The environmental goals in Flightpath 2050 recognise the need for aviation to accelerate its efforts to reduce emissions that impact climate change, noise nuisance and air quality for the benefit of the citizens and to allow sustainable traffic growth.

The UN Framework Convention on Climate Change held in Paris in 2015 (COP 21) confirmed the aim to keep global temperature increase below 2°C compared with preindustrial levels. Aviation produces around 2% of all human-induced $CO_2$ emissions. This share may seem low but it risks increasing with traffic if insufficient measures are taken.

Aviation can reduce $CO_2$ emissions by improving the fuel efficiency of the entire system through technology, operations and infrastructure but also by developing sustainable low-carbon aviation fuels.

Additional climate impacts result from nitrogen oxide (NOx) emissions and condensation trails that may lead to induced cirrus clouds.

Air quality, in particular regarding NOx and particulate matter, is also of increasing concern in and around airports.

The 2050 noise reduction objective and negative effects of noise on human health require actions on vehicle and engine design, operational and infrastructure measures, and land-use planning. Better understanding of the effects of noise on health is essential.

Production, assembly and maintenance operations consume energy and raw materials, which also gives rise to emissions and waste. Full life-cycle analysis, from concept to end-of-life using circular economy methodologies, is needed.

Securing a sustainable energy supply to match the expansion of air transport will require joint efforts by the aviation and energy sectors.

ACARE's response to Challenge 3 is covered by nine action areas:

### Action areas for Challenge 3

3.1 Develop air vehicles of the future: evolutionary steps

3.2 Develop air vehicles of the future: revolutionary steps

3.3 Increase resource use efficiency and recycling

3.4 Improve the environmental performance of air operations and traffic management

3.5 Improve the airport environment

3.6 Provide the necessary quantity of affordable alternative energy

3.7 Understand aviation's climate impact

3.8 Adapt to climate change

3.9 Develop incentives and regulations

### Flightpath 2050 goals for Challenge 3

1. $CO_2$ emissions per passenger kilometre have been reduced by 75%, NOx by 90% and perceived noise by 65% all relative to the year 2000.
2. Aircraft movements are emission-free when taxiing.
3. Air vehicles are designed and manufactured to be recyclable.
4. Europe is established as a centre of excellence on sustainable alternative fuels, including those for aviation, based on a strong European energy policy.
5. Europe is at the forefront of atmospheric research and takes the lead in the formulation of a prioritised environmental action plan and establishment of global environmental standards.

# CHALLENGE 4
## Ensuring safety and security

Responding to the demand for new and improved products and services requires a continuous stream of innovation. This will involve high levels of automation, new materials, clean propulsion fuels, and information sources that are increasingly open and shared.

Such developments bring new challenges, and if aviation is to remain the safest and most secure mode of transport fundamental shifts in thinking are needed. Moreover there is potentially much to be gained by common approaches to safety and security, so in the mid-term these areas should merge, or at least align significantly. The main actions for research and innovation in safety and security are therefore similar.

Safety strategy needs to change from being an aggregation of individual contributions to one that is holistic and multi-stakeholder. Core supporting principles for this are collaborative governance, optimised human-system interactions, better information, and systems designed and certified for safety in all conditions.

In recent years security has arguably become more of a preoccupation than safety. Although approaches for tackling security may often be similar to those for safety, there are some differences. In particular, security management structures are today weak, diverse and tend not to take a system-wide view. Moreover, mechanisms for sharing security intelligence are inadequate.

Despite the current differences between safety and security, the same five supporting principles outlined above for safety apply equally to security. Developments in both domains are similar enough to justify a collaborative approach.

### Action areas for Challenge 4

4.1 Collaborate for safety

4.2 Optimise human and organisational factors for safety

4.3 Build and exploit safety intelligence

4.4 Ensure operational safety

4.5 Design, manufacture and certify for safety

4.6 Collaborate for security

4.7 Engage aviation personnel and society for security

4.8 Build and exploit security intelligence

4.9 Ensure operational security

4.10 Design, manufacture and certify for security

### Flightpath 2050 goals for Challenge 4

1. Overall the European air transport system has less than one accident per ten million commercial aircraft flights.
2. Weather and other hazards from the environment are precisely evaluated and risks are properly mitigated.
3. The European air transport system operates seamlessly through fully interoperable and networked systems allowing manned and unmanned vehicles to safely operate in the same airspace.
4. Efficient boarding and security checks allow seamless security for global travel. Passengers and cargo pass through security screening without intrusion.
5. Air vehicles are resilient by design to current and predicted on-board and on-the-ground security threat evolution, internally and externally to the aircraft.
6. The air transport system has a fully secured global high bandwidth data network, hardened and resilient by design to cyber-attacks.

# CHALLENGE 5
## Prioritising research, testing capability and education

Aviation is a high-technology sector which combines extraordinary demands on research and innovation with long lead times. Decisions on research and technology development may have consequences on the future of the sector decades after they have been made. To maintain its world-leading position and competitiveness in the dynamic global market, Europe's aviation must be underpinned by world class capabilities and facilities in research, development, test and validation, and should provide to the current and future employees of the sector a top-level education that is adapted to its needs.

The majority of the actions described in this challenge are foundational for European aviation. This means that work needs to start immediately, defining schemes to make sure we do the right research, developing a coherent set of test capabilities and, maybe above all, providing world class education.

### Action areas for Challenge 5

5.1 Maintain awareness with an effective technology watchtower

5.2 Develop an inclusive research strategy covering the entire innovation chain

5.3 Make the right investment choices with robust selection processes

5.4 Develop and maintain state-of-the art test infrastructure

5.5 Establish a sustainable network of operators for test infrastructure

5.6 Provide world-leading education in aviation

5.7 Stimulate the involvement of stakeholders in education

5.8 Make aviation attractive to ensure inflow into educational programs

### Flightpath 2050 goals for Challenge 5

1. European research and innovation strategies are jointly defined by all stakeholders, public and private, and implemented in a coordinated way with individual responsibility. The complete innovation chain from blue sky research up to demonstration and innovation is covered.

2. Creation of a network of multidisciplinary technology clusters based on collaboration between industry, universities and research institutes.

3. Identification, maintenance and on-going development of strategic European aerospace test, simulation and development facilities. The ground and airborne validation and certification processes are integrated where appropriate.

4. Students are attracted to careers in aviation. Courses offered by European Universities closely match the needs of the aviation Industry, its research establishments and administrations and evolve continuously as those needs develop. Lifelong and continuous education in aviation is the norm.

# RECOMMENDATIONS

In 2012 ACARE identified the following recommendations in order to achieve the Flightpath 2050 goals for European aviation:

- Lead the development of an integrated resilient European air transport system that will meet the mobility needs of European citizens as well as the market needs.
- Maintain global leadership for a sector that is highly advanced and anticipated to grow.
- Establish efficient and effective policy and regulatory frameworks which ensure a global level playing field and allow European industry to prosper and compete fairly under market conditions in order to stimulate research, technology and innovation.
- Put in place incentives which are accompanied by long-term programmes with continuity across research and technology efforts over many years. This requires developing mechanisms that provide public sector investment both at European and national level, complemented by public/private partnerships.
- Champion sustainable growth so that noise and greenhouse gas emissions can be further reduced and innovative, affordable, alternative energy sources can be developed.
- Maintain the sector's safety track record and enable solutions to increasing security risks to be 'built-in' to future designs.
- Provide long term thinking to develop state of the art infrastructure, integrated platforms for full-scale demonstration and meet the critical need for a qualified and skilled workforce for today and the future.

Whilst the above still remain valid, the action areas detailed in this document identify the following additional recommendations:

- Enable integration of RPAS (remotely-piloted aircraft systems) ensuring that safety and security risks are addressed
- Develop and exploit advanced manufacturing technologies with new industrial paradigms
- Harness the deployment of advanced IT capability and big data taking into account security challenges
- Ensure that the entire research and innovation chain is covered and supported by appropriate measures, financial, policy, regulatory, environmental and so on.

The challenging goals of Flightpath 2050 can only be delivered if all ACARE stakeholders work together to ensure that research and innovation through collaborative programmes is undertaken on both European and national levels.

ACARE has demonstrated the strength of working closely together across the whole aviation community including air transport, the manufacturing industry, research establishments, universities, regulatory authorities, member states and the European Commission. These stakeholders are committed to playing a pivotal role in collaboration and cooperation at European and global levels.

Today Europe is a world leader in aviation: The SRIA represents a vital contribution to maintaining and expanding this excellence in the future and provides guidance on the research, development and innovation needed to deliver the Flightpath 2050 vision.

# VOLUME 1 IN DETAIL


ADVICE TO PASSENGERS
check-in

# CHALLENGE 1
## Meeting societal and market needs

The customer is at the centre of the mobility vision set out in Flightpath 2050. This means that passengers, freight forwarders and shippers must be the clear focus of the transport sector in which aviation is a key player. This requires a paradigm shift from the current perspective, centred on the service provider, to one in which the customer comes first.

Operators must provide a service on each segment of the door-to-door journey with the highest possible level of performance and predictability. Core values in an advanced and innovative transport environment are collaboration, co-operation and data sharing giving customers access to correct, timely and unbiased information. Society requires seamless connection across the different transport modes that make up a door-to-door journey. In summary, meeting societal and market needs is about true journey-wide customer-centric mobility for both passengers and freight.

Efficient and sustainable mobility is an essential enabler for Europe's economic development and social well-being. Good connectivity is a precursor to wealth and prosperity, cohesion, international relations and stability. It is also a strong stimulant for local employment, both direct and indirect.

Mobility is not just needed for travel to work and for other business purposes, but is also nowadays an important social expectation. Increased free time, more disposable capital, and friends and relatives dispersed across the globe give rise to a relentlessly increasing demand for leisure and tourist travel. Improved mobility is a key enabler to further the integration of the European Union.

Air transport must continue to support economic growth and add value at European, regional and local levels by providing the service and connectivity required by businesses and individuals. This must be facilitated by the design and implementation of a resilient, sustainable and customer-centric intermodal transport system that meets European mobility goals.

**Design of a customer-centric intermodal transport system:** An integrated and intermodal transport system must be designed around future customer expectations, roles, profiles and societal acceptance factors. Market changes and opportunities must be fully embraced. In this context issues to be addressed include system architecture, interoperability standards, regulatory frameworks and network management needed for robust operations.

In order to meet mobility performance goals it is necessary to develop assessment, monitoring and forecasting capabilities for new concepts, infrastructure and demand scenarios.

**Travel process management:** This will provide the customer with simple means such as a single ticket for an entire journey. Travel information that is unbiased, robust, relevant and complete must be available both before and during the journey.

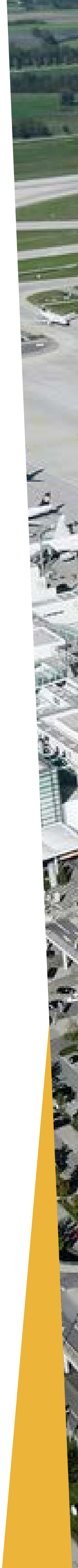
It also involves enhanced crisis management and resilience to mitigate the impacts of different types of disruption. A robust management and recovery mechanism will protect customers' rights and interests.

**Integrated air transport:** Major change is needed to aviation ground infrastructure in order to offer customers a vastly improved, seamless travel experience. This applies to airports, urban helipads and facilities to support new air vehicles and concepts. Infrastructure changes must be done with due consideration of the impact on local communities.

Aviation ground nodes must evolve into intermodal hubs for easy transition between surface and air transport, this is essential if overall transport performance needs are to be met.

Air traffic management must find innovative ways to provide services to an increasing population of airspace users in a safe and efficient way: capacity must be available to accommodate increased demand and vastly improved predictability of operations in all weather conditions. All classes of air vehicles must receive appropriate and timely strategic and tactical air traffic services and supporting information.

All this needs to be supported by high-performance, integrated communication, navigation and surveillance systems and infrastructure. Underpinning performance will be automation, autonomy, big data and system intelligence in a structure designed for resilience.



| ACTION AREA | | 2050 TARGET STATE |
|---|---|---|
| 1.1 | Understand customer, market and societal expectations and opportunities | Understanding customer, market and societal expectations and opportunities has led the development of a customer-centric transport system. New processes, technologies and services are built on these expectations and opportunities with agreed rules for data sharing, increased automation etc. |
| 1.2 | Design and implement an integrated, intermodal transport system | The transport system is customer-centric, integrated, energy-efficient, diffused, resilient and intermodal. It provides a variety of services and options for customers to choose from based on individual preferences. It takes travellers, their baggage and freight from door to door, safely, affordably, quickly, smoothly, seamlessly, predictably and without interruption. |
| 1.3 | Develop capabilities to evaluate mobility concepts, infrastructure and performance | Mobility performance is highly predictable and transparent for customers. On a network level, mobility performance is monitored and assessed on a constant basis with agreed metrics. The effect of new mobility systems, infrastructure scenarios or mobility patterns is analysed and predicted based on agreed criteria resulting in timely provision of required transport infrastructure. |
| 1.4 | Provide travel management tools for informed mobility choices | Customers are served by a fully integrated travel management solution, enabling them to establish a single-point transport contract for door-to-door services with a single ticket for the entire journey. |
| 1.5 | Deliver mobility intelligence: journey information, data and communication | Real-time data drawn from many sensors supports the successful completion of the customer journey. High speed data connections enable continuous access to data and applications for work or leisure through the entire journey. Customers receive dynamic information at all stages of the journey. |
| 1.6 | Provide tools for system and journey resilience, for disruption avoidance and management | When disruption occurs, journey management systems provide passengers with real-time information and journey reconfiguration, including change of mode. Resilience is improved by predictive tools to ensure service continuity, as well as collaborative mechanisms to enforce mobility plans under disruptive events. |
| 1.7 | Evolve airports into integrated, efficient and sustainable air transport interface nodes | Airside and landside processes at airports are optimised for customer comfort, predictability, performance and better integration of transport modes. Revolutionary air vehicles and aviation technologies are integrated into existing infrastructure. New air transport interface nodes have been designed where existing capabilities were inadequate. Airport access has been improved through an innovative approach towards safe, efficient, frequent, comfortable transport systems and services. |
| 1.8 | Design and implement an integrated information, communication, navigation and surveillance platform | A new integrated information, communication, navigation and surveillance platform has been implemented. This includes innovative infrastructure concepts to address intermodality and performance, satisfying the needs of all air vehicle types and missions. |
| 1.9 | Develop future air traffic management concepts and services for airspace users | New operational concepts and new aviation services are in place accommodating all air vehicle missions and aerial applications in a high performance, agile system. They adapt to optimise air vehicle operation, fleet operation and flows in accordance with performance-driven requirements. New business models and regulatory measures facilitate innovative and performance-driven services to airspace users. |
| 1.10 | Address cross-cutting issues: system intelligence, human factors and automation support, autonomy and resilience | Concepts, procedures, systems and technologies are available to address cross-cutting issues like system intelligence applications, human-centred automation, autonomous/automated operation concepts, systems and interfaces including certification and responsibility issues and ATM resilience. |

# ACTION AREA 1.1
## Understand customer, market and societal expectations and opportunities

The transport system of the future will be designed with the customer at its centre. **The needs of passengers, freight forwarders, shippers and other users will define the requirements**. Their profiles, expectations and intended roles must therefore be fully understood with a view to delivering the best possible door-to-door travel experience.

Current and future **socio-economic factors and forces** will potentially have major implications for the transport industry; these must be analysed and taken into account. Understanding customer, market, and societal expectations and opportunities covers many different aspects.

Research is needed to develop a comprehensive view of **people's attitudes and expectations concerning transport systems of the future**. Societal and market research will yield key factors that will be used to shape concepts and designs. It will also be necessary to consider regulatory aspects that may be needed to support or influence developments.

The challenges of implementation, deployment and exploitation are of a different nature from those in technical system development, so it is important to understand **societal acceptance factors**. These will be key to enabling successful deployment and operation of new systems and technologies into the market.

A further consideration is the **increase of automation and autonomous (airborne) operations**. Acceptance of these is critical and must be built on an understanding of the regulatory and legal implications of changes in responsibilities, rights and obligations of operators and the general public.

The operational and legal implications of integrating unmanned and other innovative aerial vehicles into civil airspace must also be fully identified.

Aviation and transport markets have their own specific challenges since they need to consider local, regional and global dimensions. In this context research is needed to understand how competitiveness with a **level playing field** can be assured.

An integrated transport system relies on very high levels of cooperation and data sharing across all transport stakeholders, who are sometimes in competition. For this, **business cases** must be developed spanning multiple stakeholders, and political instruments and incentives may need to be developed.

It is vital to carefully consider **customer and stakeholder data management** from the perspectives of privacy and security. Specific data and information services will need to be developed for an integrated transport system. Powerful safeguards must be built in to ensure the integrity of private data and ensure personal dignity. These must be sufficient to gain customer confidence to ensure acceptance.

Finally, societal and market demand and acceptance factors for **low carbon transport systems**, essential for sustainability, must be fully understood and incorporated into future designs.

This action area covers foundational topics so research should start as soon as possible and be well underway in the 2020+ timeframe. Since the success of innovation in many domains will benefit from the results, clear messages should be available before 2030.

### Expected impact

These actions will result in more focused research and development, better chances of successful deployment, more effective use of resources, shorter innovation cycles and greater invention. Most importantly, they will place the customer at the centre of the transport system.

# ACTION AREA 1.2
## Design and implement an integrated, intermodal transport system

In order to satisfy customer needs and expectations, it is essential to design a door-to-door transport system that is fully integrated across all modes: air, rail, road and maritime. The design must take into account emerging market developments, societal acceptability criteria and regulatory constraints. It needs to **provide seamless door-to-door transit for passengers, baggage and cargo**. Key elements are flexibility and robustness to support constantly evolving requirements, technologies, vehicle types, business models and boundary conditions across all transport stakeholders.

Constant monitoring will be needed to **ensure customer-centricity** regardless of mode of transport. A large quantity of yet-to-be-defined data will have to be exchanged, and collaborative mechanisms developed between potentially competing stakeholders to support seamless door-to-door journeys. **Interoperability requirements and standards** will need to be agreed and implemented for all technical and operational systems that interface with each other.

**Transport and journey management functions** must be accommodated at architectural and design stages. They must enable cross-modal optimisation, robustness and resilience including dynamic reconfiguration in the case of disruption or unforeseen incidents. Mobility must be assured during abnormal conditions, especially for public service and emergency situations. The design and costs to support this must be accepted and shared across cooperating modes.

Significant research is required to set up the **basic architecture of an integrated intermodal transport system**. This will need a holistic, end-to-end analysis with perspective over the entire journey, and will integrate information and operational procedures from the different modes. This is non-trivial, since it needs to take account of competitive interests, natural and statutory monopolies, and local, regional and global aspects.

The system must benefit from a **level playing field** relative to other major (transport and non-transport) industries in terms of cost, environmental assessment, taxation, regulatory burden, and public subsidy. It will balance public service obligations, especially to remote and peripheral regions, with competition and market realities.

The integrated, intermodal transport system will not become a reality without overarching **regulation** setting the framework conditions for design, implementation and operation. This will require substantial analysis and research.

The focus of this action area is therefore the design of an integrated, intermodal transport system to best meet the various requirements of all customers and stakeholders. Research will support this, and will furthermore address innovation, policy, regulatory needs, business case, implementation and deployment, and customer and market acceptance.

In setting up a basic architecture it will be necessary to foster agreement, initially political then technical, between transport modes. This will cover operational concepts and possibly the conditions of a regulatory framework. These are fundamental steps towards a fully integrated transport system, and therefore should be initiated as soon as possible and be mature before 2030.

### Expected impact

An adopted architecture providing an operational and technical framework, together with basic regulatory support are key requirements for the implementation of a customer-centric door-to-door-transport system.

# ACTION AREA 1.3

## Develop capabilities to evaluate mobility concepts, infrastructure and performance

Flightpath 2050 envisages ninety percent of travellers within Europe completing their journey, door-to-door, within four hours. Support and monitoring to allow achievement of this target is needed, and is described in this action area.

A key necessity in a fully intermodal system will be to **understand and evaluate door-to-door mobility performance**. For this we need detailed data, analysis and forecasting capabilities for mobility flows, assessing the contribution of each transport mode and its supporting infrastructures. This must be extendible to new concepts.

**Performance evaluation** should take place on a single, integrated platform that can set baseline targets for achievement of the four-hour goal, and then forecast, measure and validate progress towards it. The analyses will be based on journey, traffic and infrastructure data collected in real-time, as well as mobility flow forecasting tools.

It must be able to work both at a detailed scale, allowing analysis of performance over single journeys, and also at a macroscopic level, to evaluate multiple, complex journeys that use different operators, transport modes and infrastructures.

**Customer-oriented performance metrics** must be carefully chosen so that they are also capable of assessing future demand and infrastructure scenarios.

It must be possible to apply the evaluation capability to **new and planned (intermodal) mobility concepts**. This will help to identify and address design and implementation challenges at an early stage.

Mobility performance is inherently linked to **ground and air infrastructure availability and capacity**. The evaluation capability must be able to perform assessments for various infrastructure scenarios giving it a role in infrastructure network planning taking into account door-to-door mobility choices.

Innovative ways for reaching **societal consensus** must be found for the construction, expansion and operation of air transport infrastructure. An evaluation capability will help by clearly demonstrating the expected benefits of mobility performance and resilience.

This action area requires significant research to define metrics and implement a modelling and evaluation capability for intermodal mobility performance. This should be able to operate on local and European scales for a wide range of future input scenarios and real data.

The evaluation capability described here will persist and evolve over time to accommodate new concepts and real-world developments. However, due to its importance for assessment and forecast of mobility performance, initial capabilities are required in the 2020s with full functional capability to be achieved in the 2030s. Constant evolution and adaptation to state–of-the-art technology will be required following initial implementation.

### Expected impact

The evaluation capability is vital to support the development of a future multi-modal door-to-door transport system that answers the needs of the customer. It will enable key decisions at each stage of the process from research planning to policy and infrastructure choices.

# ACTION AREA 1.4

## Provide travel management tools for informed mobility choices

A customer travel management toolset capable of delivering the relevant information before and during a journey is essential to support future mobility concepts. It will enable customers to **make informed transport and mobility choices** for their door-to-door journey according to their preferences, based on a sound and transparent logic.

As a first step it is necessary to define **metrics, concepts and methodologies for unbiased assessment of the different transport options**. A regulatory framework will be necessary to support collection and sharing of required data.

The toolset must allow **journey planning door-to-door across multiple modes according to customer preferences**, using different operators if needed. This needs to be done in an unbiased way that provides the best solution with clear and transparent information on customer-selected criteria. New functionalities will be required such as intermodal journey planning and pricing.

Customers must be provided with a **single entity to assume accountability and responsibility** for their journey. This is particularly important where multiple modes and service providers are involved. As such, governance rules will also have to evolve for example with regard to cost allocation and compensation obligations between the different stakeholders.

It should be possible to make reservations and payment for the complete journey in a single transaction. A **single ticket**, electronic or otherwise, valid for the entire journey, should then be issued.

Further recommendations may be provided to the traveller at any time during the course of the trip.

There is strong interdependency between travel management tools and other action areas under the 'mobility' challenge. Consistent overall architecture, common metrics and enhanced information (Action areas 1.2, 1.3 and 1.5) are therefore essential.

The visibility provided by travel management tools has wider implications across the entire travel industry since they will give customers a clear, unbiased view of the offers and responsibilities of all providers across all modes. As well as increasing competition, this will bring pressure for cooperation.

Collaboration across all modes should be initiated immediately and matured in the 2020 timeframe. This will allow realisation of the functionalities during the late 2020s. Constant update and adaptation will be necessary after initial implementation, for which the architecture and design of the system should make provisions.

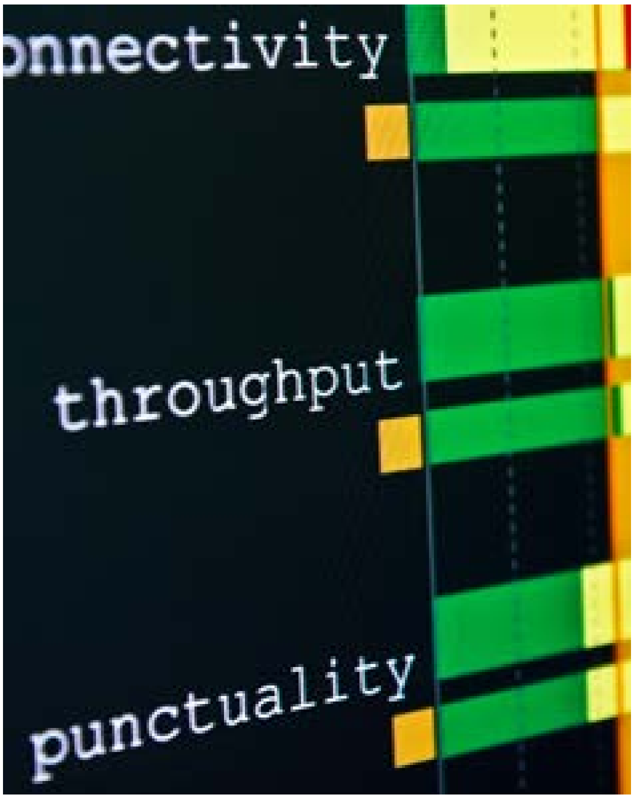
### Expected impact

Providing the customer with a transparent view of travel options, costs, and the responsibilities of service providers across modes will provide a powerful force for improved customer experience and ensure quality of service over the entire door-to-door journey.

# ACTION AREA 1.5

## Deliver mobility intelligence: journey information, data and communication

Customers need comprehensive information that will allow them to properly **manage their journeys in real time**. Informed mobility choices require information that is trustworthy, accurate, reliable and timely. This must cater for all eventualities and may require **unprecedented availability and sharing of operational, private and sometimes commercially-sensitive data**.




**In-journey tracking and status of current or planned stages** must be shared in real-time. In particular, delays and disruptions must be presented allowing, if necessary, re-planning of one or more segments. All this must apply in a seamless way across all modes, and over the entire trip.

The information system must be built on **real-time data drawn from all available sensors**, including the customers themselves, from all modes of transport. Standards for the exchange of such data between the different modes and service providers must be developed. A **regulatory framework** may be required to ensure that data are collected, shared and used without jeopardising commercial interests. Data privacy and security must be assured at all times.

Sciences of **data management, big data and predictive analytics** together with higher computational performance bring significant possibilities for this application. New cryptography algorithms (e.g. blockchain) may change the nature of business transactions and solve privacy-related issues. Information technology with biometry-based identification and payment systems may be of benefit for different parts of the journey.

Underlying these applications will be robust, high-speed and secure in-journey communication links for which significant progress has already been made. Multi-channel notification capabilities and systems will ensure relevant, timely and personalised information to passengers at all stages of travel.

The foundation of these capabilities is data, so **common requirements must be developed and agreed across modes and service providers**. Standards will then be needed to cover all aspects of acquisition, processing, confidentiality and security.

There is strong interdependency between mobility intelligence tools to support customer travel management and other action areas that form part of the mobility challenge. Consistent overall architecture and common metrics (Action areas 1.2 and 1.3) are essential.

This action area addresses a basic requirement for the customer, so data policy and standards should be available in the early 2020s. This should be accompanied by regulatory actions if needed. Constant adaptation over the years to accommodate technical and market developments will be required. Full intermodal intelligence should be envisaged in the 2035 timeframe.

### Expected impact

Providing the customer with high-quality mobility information and intelligence will not only improve the travel experience but will also provide a powerful force for better quality of service over the entire door-to-door journey.

# ACTION AREA 1.6

## Provide tools for system and journey resilience, for disruption avoidance and management

Disruption is one of the most frequent sources of traveller dissatisfaction, with lack of information the most common complaint. **Management and recovery mechanisms** are therefore required to ensure successful completion of door-to-door journeys in cases where one or more segments cannot be executed as planned.

**Resilience and mitigation against disruption** must be designed into the system at the earliest possible opportunity, considering both technical and operational aspects. Unexpected events do occur however, and in these cases customers have a right to expect timely information and guidance that supports and protects their rights and interests. In order to minimise the likelihood and effects of disruptions, research should address **predictive and prognostic disruption forecast methods in support of pro-active mitigation**.

As far as possible, passengers must have **information on actual or predicted disruptions** ahead of their departure and throughout the entire journey. Intelligent tools must pinpoint issues in any segment of the journey, notify the customer and, if the issues are grave, suggest suitable alternatives using the most effective mode(s) of transport.

Acceptance of a proposed alternative journey option must be simple. **Journey reconfiguration** including cancellations, re-bookings, refunds and compensation need to be processed automatically. Costs must be redistributed automatically between the different service providers.

Disruption management should be supported by **legislation that ensures a level-playing field for all modes of transport**. Passenger rights must apply across all modes, covering the door-to-door journey.

Widespread disruption events, or crises, may require **system-wide contingency planning and/or crisis management** that form an overarching context for individual passenger processing. For such eventualities there must be an agreed framework of actions that protects and supports customers so they can effectively manage and implement their individual solutions.

**Mobility plans to ensure service continuity** have to be defined for all known or envisaged types of large-scale disruptive events. Plans must consider prioritisation of available capacity and be cooperative across all stakeholders and with the relevant authorities.

Plans may include provision for temporary rules, freedoms or obligations to allow effective and pragmatic management of the situation. They must also make provision for speedy reversion to normal operations.

Research is therefore needed on the resilience aspects of the transport system, on the prediction of disruptive events and on in-journey passenger tools for the detection and management of disruption.

Policy and legislative involvement may be needed to ensure that the customer is given proper priority, and to ensure collaboration across the different modes.

Research can start immediately; initial capabilities can be available in the late-2020s timeframe with full potential realised by the mid-2030s. Constant adaptation to state–of-the-art technology will be required after initial implementation.

This area is closely linked to others under this challenge.

### Expected impact

Disruptions and crisis situations happen. Tools that allow their intelligent management and improve journey resilience are a key requirement for meeting customer expectations and achieving the goal of four hours door-to-door travel.

# ACTION AREA 1.7

## Evolve airports into integrated, efficient and sustainable air transport interface nodes

Achievement of Flightpath 2050 mobility goals is critically dependent on the provision of sufficient supporting ground infrastructure. Air transport interface nodes include airports, vertiports and any other ground infrastructure supporting airborne passenger or cargo services. Also covered is infrastructure that interconnects to other transport modes.

**Processes for passenger, baggage and freight handling** must be continuously improved. Better performance must be achieved in punctuality, predictability, delay, waiting times, convenience and availability of information. Much improved integration with other transport modes is another important requirement.

Progress should be based on the analysis of logistics processes across the entire airport system. Innovative, collaborative decision-making, built upon total node (airport) management is required to create seamless passenger and cargo concepts, technologies and procedures. This must be supported by specially adapted performance metrics.

In addition to process optimisation, research is required **for improved air transport interface node (airport) design** to deliver the best possible customer-centric infrastructure layouts that integrate seamlessly with other transport modes. **Airport access** must be efficient with frequent, comfortable and stress-free transport options available.

Provision must be made airside for the **technological and procedural integration of new aviation technology and future air vehicles**. This may include short- and vertical-take-off and landing aircraft, remotely-piloted aircraft systems (RPAS), super- and hyper-sonic vehicles. New infrastructures or processes are to be designed where existing capabilities are inadequate. Given the long lead times, radical new aviation developments and equipment must be notified sufficiently in advance for effective and timely integration into ground infrastructure.

In summary, this area primarily concerns research for further optimisation of airport processes and infrastructure, with particular emphasis on integration with other transport modes. Attention should be paid to the accommodation of new (air) mobility concepts and technologies.

This area builds upon the ATM Masterplan and SESAR Solutions.Therefore research into airside operations should be programmed post-SESAR 2020 and built upon relevant exploratory research. However, research to improve intermodal infrastructures and procedures, currently outside the scope of SESAR, is needed immediately.

Support to accommodate new air vehicle types must be studied as soon as possible, preferably at their conceptual stage. This is already the case for remotely-piloted systems.

Note: Environmental aspects of aviation ground node operations are covered in Challenge 3.

### Expected impact

The aviation network is critically dependent on highly efficient and integrated ground interfaces. Improvements in this area are therefore foundational, impacting the entire system.

# ACTION AREA 1.8

## Design and implement an integrated information, communication, navigation and surveillance platform

New concepts for a cost-effective information and communication infrastructure are required to meet all aviation performance requirements. Key considerations are bandwidth (data capacity), safety, security and quality of service.

The concept of system-wide information management, currently part of SESAR developments, should evolve into a **comprehensive information management network**. Information services should be fully decoupled from physical channels and must be based on network architectures that support the introduction of innovative services and facilitate market access to new entrants.

**Quality-assured information** needs to be exchanged using consistent data that is derived, integrated and fused from a number of independent sources. Greater interconnectivity and integration increases the focus on the crucial importance of cybersecurity – this is dealt with in Challenge 4.

Communication, navigation and surveillance systems and infrastructure must take a more **business-oriented approach** so that resources are used more efficiently, delivering the required capability in a cost-effective and spectrum-efficient way.

A **performance-based navigation and surveillance information platform** is envisaged. This will increasingly rely on satellite-based technologies with multi-constellation, multi-frequency augmentation systems. It will be available throughout the global network to meet the needs of future operations. The platform must accommodate, inter-alia, RPAS (remotely-piloted aircraft systems), ensuring low cost, robust navigation support with global coverage.

**Advanced navigation technologies using new sensors** are needed to allow flexible and sustainable operations, in all weathers and atmospheric disturbances. Research is needed into electronic countermeasures against GNSS jamming, spoofing and other security threats.

**New surveillance techniques and procedures** are needed to improve the provision of continuous and accurate air vehicle position information. Secure integration of diverse cooperative and non-cooperative surveillance technologies from disparate sources will be required.

Timely development and introduction of **global airworthiness and interoperability standards** is essential.

The focus of this area is research and innovation in the fields of technology, systems and procedures. This must deliver a spectrum-efficient integrated communication, navigation and surveillance infrastructure that satisfies all system requirements. Security considerations are key.

This area builds upon the SESAR ATM Masterplan and SESAR Solutions, therefore research must be targeted to follow the current programme with new concept development in the 2025 timeframe and implementation targeted at 2035 or later.

### Expected impact

An integrated communication, navigation and surveillance platform will be a foundational element of the air transport system of the future.

# ACTION AREA 1.9

## Develop future air traffic management concepts and services for airspace users

Flightpath 2050 challenges air traffic management services to double the available capacity while improving safety and efficiency and reducing environmental impact. The future system must also be able to accommodate new types of aerial vehicle and cope with more complex demand patterns, especially in extended metroplex airspace.

This calls for **new concepts for an agile, resilient system** covering all operations from strategy and planning through to tactical control. **All vehicle missions and aerial applications** must be accommodated, unintended use of airspace prevented, and the impact of weather and other disruptions minimised.

**Performance-based operations** must be designed to allow aircraft to fly the most efficient route and profile, ensuring lowest-possible emissions. Safe separation should be supported by advanced avionics and integrated communication, navigation and surveillance systems (see previous action area).

**Fully integrated collaborative decision-making** will be needed for all phases of flight encompassing all airspace stakeholders. This will allow balancing and prioritisation of stakeholder interests supported by system-wide analyses, trading rules and assistance tools.

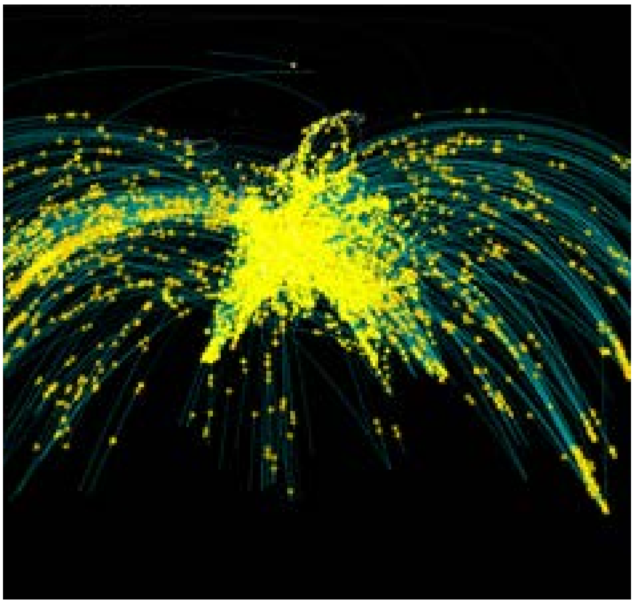
**Network congestion management and recovery mechanisms** must be identified and implemented. Network-wide optimisation must be effective for all vehicles and operators ensuring the best trade-off between the different performance goals.

**System status and performance data** must be widely available allowing airspace users to dynamically adapt air vehicle and fleet operations according to their needs and priorities. Measures should be available in near real-time to allow high reactivity.

Research is needed to find the **most efficient and fairest operational schemes** such as best-equipped-best-served or on-time-first-served. Airports need effective airside models that optimise across several criteria such as noise, emissions and capacity in response to current operating conditions.

Innovative and competitive services for airspace users must be supported by **international agreements and possibly legislative and regulatory measures**. These must be adapted for future market needs and supported by strong governance, institutional and economic frameworks.

In this respect there is a need to consider **new business models** for service provision, and for the management of the new integrated communication, navigation and surveillance infrastructures. Incentive mechanisms may be required to promote coordinated adoption of new technologies.



The focus of this action area is on research into all technological, operational and institutional elements of the air traffic management system. It builds upon the SESAR ATM Masterplan and SESAR Solutions, therefore research should start in the 2025 timeframe and be targeted for implementation from 2035 onwards. New research should build upon works done in the SESAR2020 exploratory research programme.

### Expected impact

Performance-based, future-proof, robust and safe air traffic management and its supporting technical services are key enablers for the air transport system of the future.

# ACTION AREA 1.10

## Address cross-cutting issues: system intelligence, human factors and automation support, autonomy and resilience

This area deals with transversal issues and therefore may be generally applicable to many parts of the aviation and transport industry. Aspects of particular interest to the scope of the mobility challenge are highlighted here. Safety and security are covered in detail under Challenge 4.

**System intelligence** refers to intelligent behaviour within a complex system involving interaction and feedback from all parts of that system. It is a new field that can benefit automation at all levels, right up to the highest levels of autonomy. Research is required into applications that could support many areas described within this challenge: mission management, air vehicle or airport operations, travel and traffic management, network management, air vehicle maintenance, decision-making support, crisis management and traveller assistance.

It is essential to **better understand interactions between humans and highly automated systems**, and to design effective interfaces towards a true human-machine partnership. Automation systems and their interfaces should adapt to individual human performance. Where appropriate, machines should provide visibility on guidance and decisions generated by the automation. Attention must be paid to all aspects of human factors, theory, methods and implications of decision support systems in particular with regard to degradation of automation.

With the advent of **higher automation and collaborative multi-stakeholder decision-making** in a connected environment, requirements for **selection, training and qualification** will evolve. In this respect due consideration must be given to social context and culture to ensure that all staff are well prepared for new and emerging design and operational paradigms.

All of the above must apply particularly in the context of a **substantial increase in the number of RPAS (remotely piloted aircraft systems)** that will be operated in the near future.

System intelligence and high automation can only work if properly supported by common guidelines, and possibly regulation. The share of authority and responsibility between different actors, pilot, controller or machine, needs to be clearly set out, with an emphasis on human-centred automation. By the same token it is also necessary to address certification and liability issues.

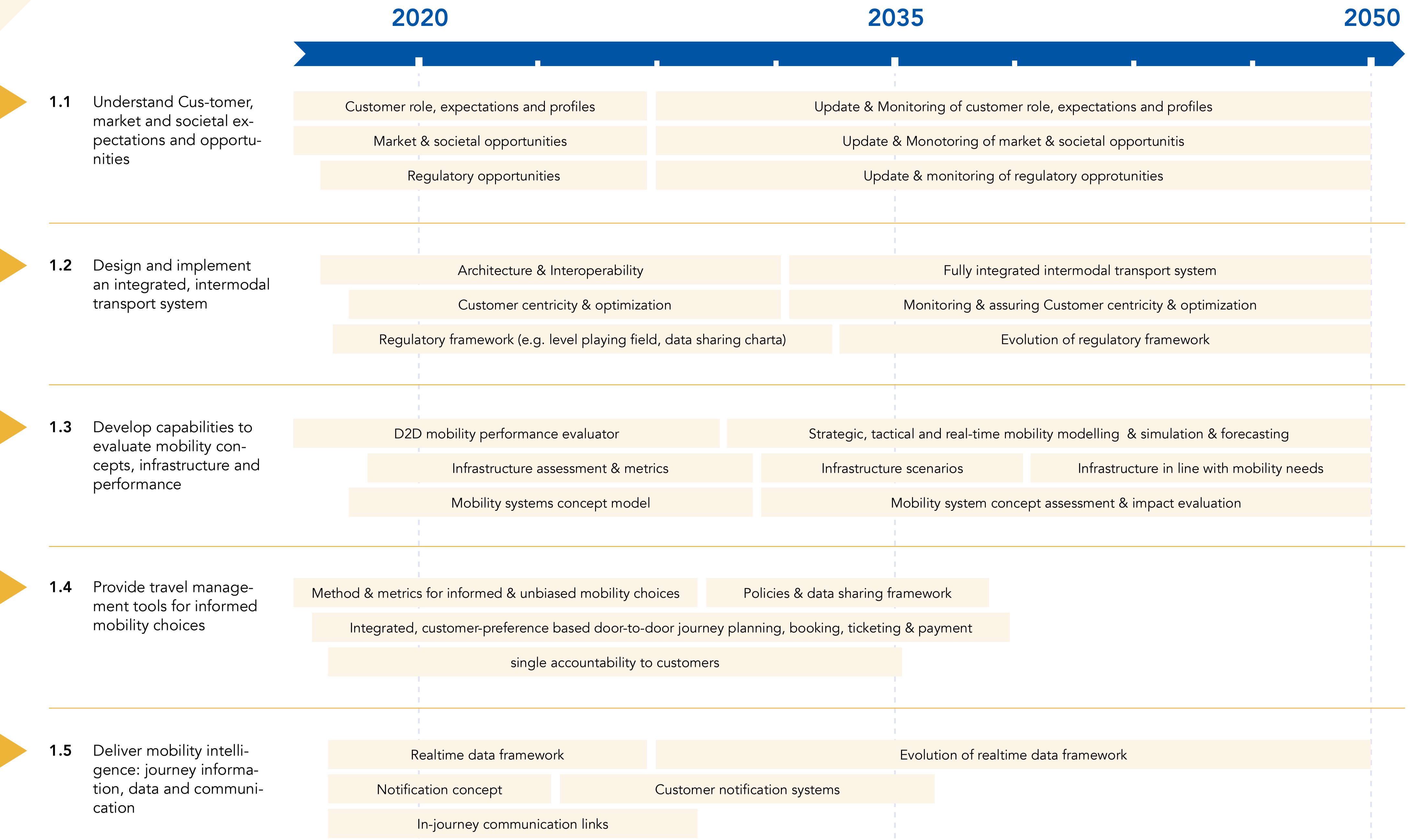

Finally, it is necessary to better model and implement resilience across the air traffic management system. This will require both organisational and technical provisions to allow the system to properly deal with both small- and large-scale disturbances.

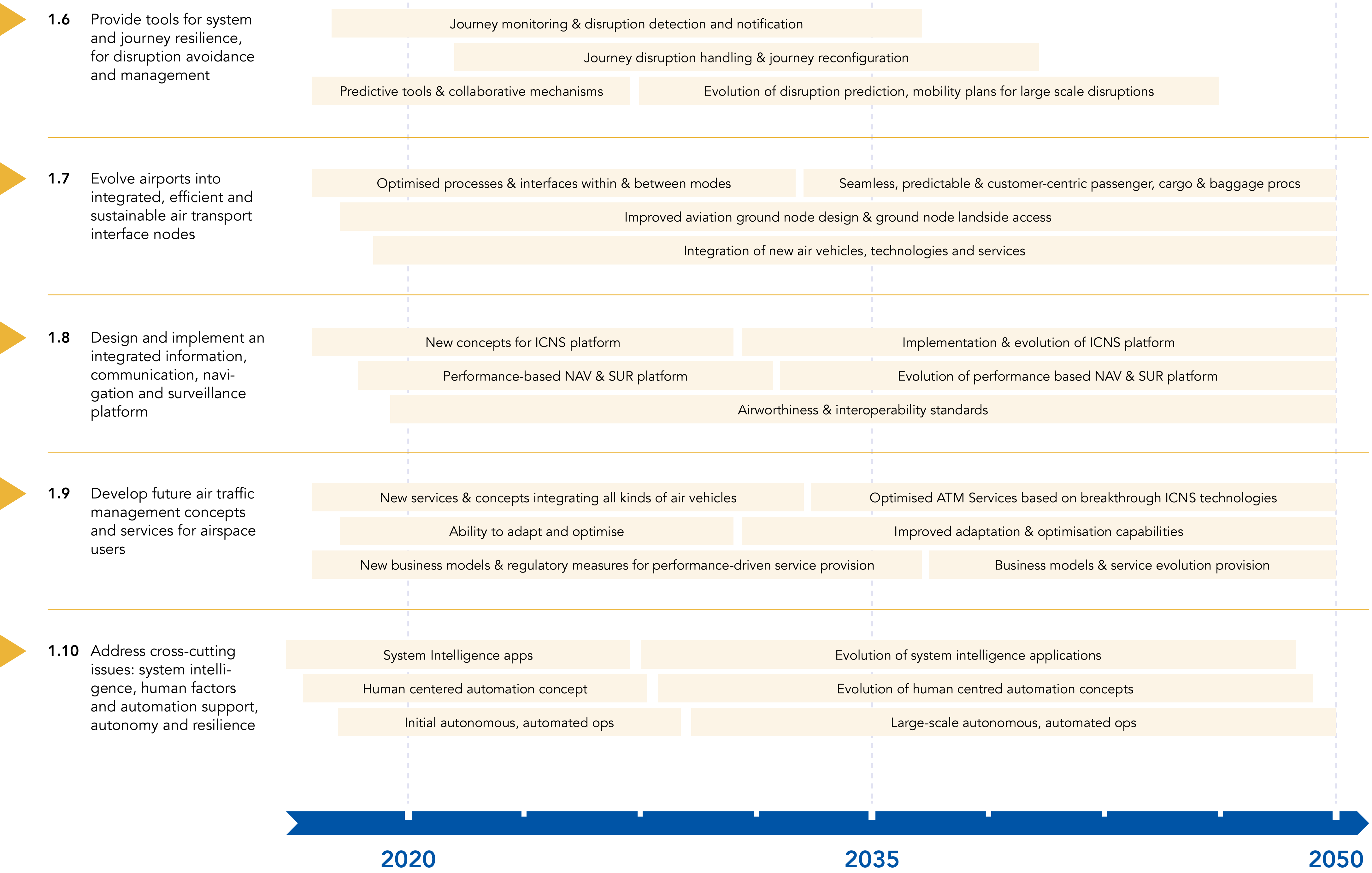
Much foundational work has been done in the SESAR and Clean Sky programmes and elsewhere. However, this action area is relevant across all parts of the aviation sector. These transversal aspects must be constantly developed and adapted for the benefit of aviation, keeping up with new concepts, and exploiting new science.

### Expected impact

System intelligence, automation and autonomy, correctly exploited, can provide breakthrough gains in performance and safety across the air transport sector. Developing a proper foundation for their design, development and implementation will maximise benefit and minimise risk.

# Timeline for Challenge 1: Meeting societal and market needs




1.6 Provide tools for system and journey resilience, for disruption avoidance and management
Journey monitoring & disruption detection and notification
Journey disruption handling & journey reconfiguration
Predictive tools & collaborative mechanisms
Evolution of disruption prediction, mobility plans for large scale disruptions
1.7 Evolve airports into integrated, efficient and sustainable air transport interface nodes
Optimised processes & interfaces within & between modes
Seamless, predictable & customer-centric passenger, cargo & baggage procs
Improved aviation ground node design & ground node landside access
Integration of new air vehicles, technologies and services
1.8 Design and implement an integrated information, communication, navigation and surveillance platform
New concepts for ICNS platform
Implementation & evolution of ICNS platform
Performance-based NAV & SUR platform
Evolution of performance based NAV & SUR platform
Airworthiness & interoperability standards
1.9 Develop future air traffic management concepts and services for airspace users
New services & concepts integrating all kinds of air vehicles
Optimised ATM Services based on breakthrough ICNS technologies
Ability to adapt and optimise
Improved adaptation & optimisation capabilities
New business models & regulatory measures for performance-driven service provision
Business models & service evolution provision
1.10 Address cross-cutting issues: system intelligence, human factors and automation support, autonomy and resilience
System Intelligence apps
Evolution of system intelligence applications
Human centered automation concept
Evolution of human centred automation concepts
Initial autonomous, automated ops
Large-scale autonomous, automated ops
2020
2035
2050

# CHALLENGE 2
## Maintaining and extending industrial leadership

Competition is becoming ever more fierce, not only from established sources, such as the United States, but also from recently emerged and emerging challengers, such as Brazil, Canada, China, India, the Gulf States and Russia. These countries understand the strategic nature of aviation and support their industries accordingly. This impacts the competition between countries as well as between companies.

Even though the global aviation market is increasing in size, Europe must preserve its pre-eminent position to ensure the continued success and economic contribution of its aviation industry by investing continuously and heavily in key enabling innovation, research and technology supported by adequate policies and frameworks. Financial and human resources are abundantly available in the emerging competing regions, and Europe must increase and focus its resources to maximise its potential within the timeframe of Flightpath 2050.

Furthermore, new business models are changing the ways in which innovation, research and technology are being funded by third parties. Additional game-changers include reduced costs for entry to the sector, and greater use of digital and data-based business models for value creation. This provides opportunities for the European aviation sector to exploit its capabilities globally via strong industry alliances and emerging new entrants.

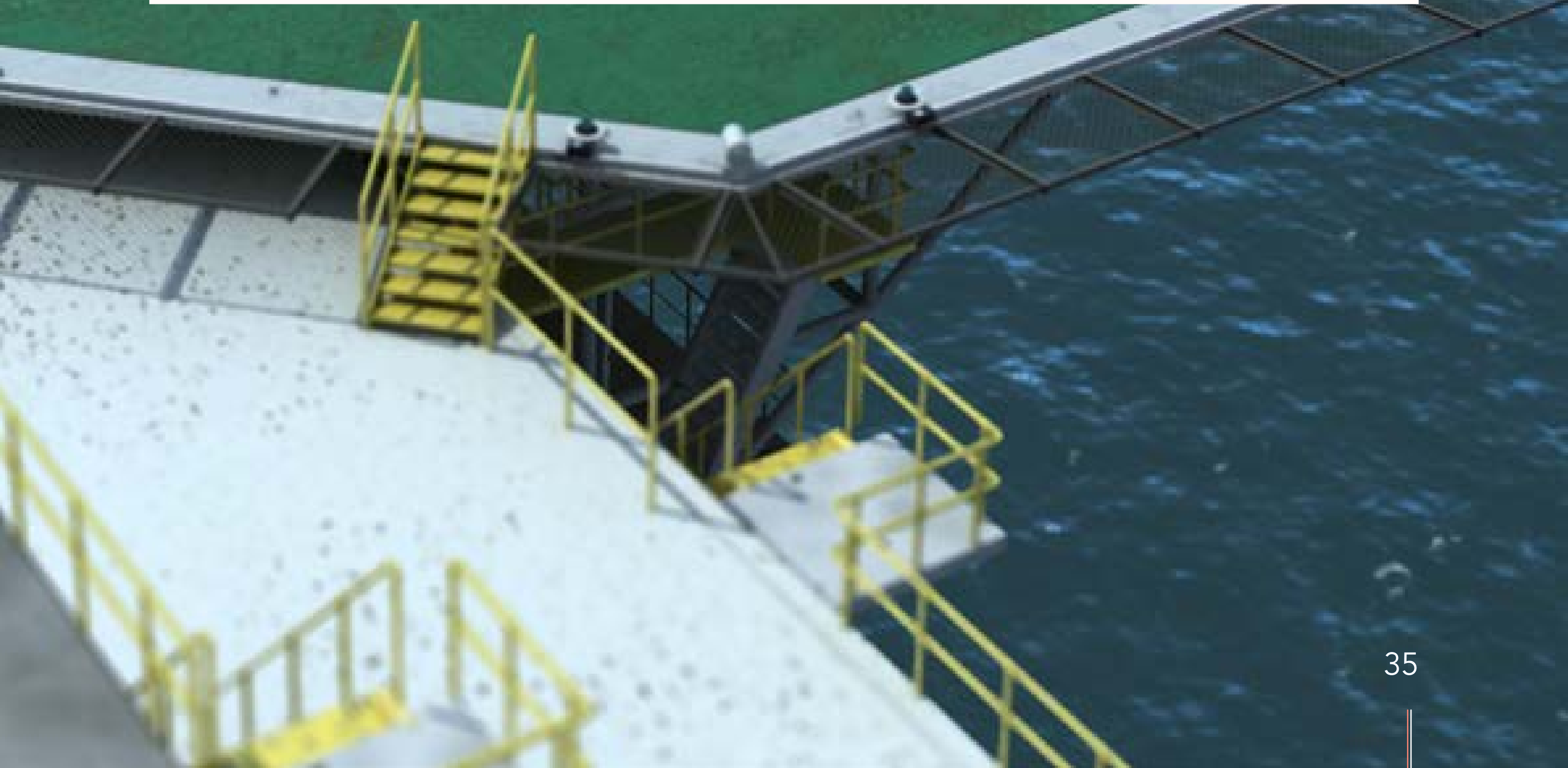
To maximise these opportunities European aviation must position itself as the preferred partner for global innovation, research and technology. It must encourage start-ups, supporting the existing ecosystem and enabling more data-driven and digital environments.

The fast-evolving globalisation of aviation also presents a risk for retention of human resources in a highly competitive environment. Europe must position itself with policies and frameworks to attract and retain the best talent to ensure world-class innovation, research and technology development.

Technological leadership and innovation is becoming the major competitive differentiator, most notably in terms of energy and environmental performance. The future is not guaranteed without sustained or increased investment in the technologies of tomorrow. The market demands shorter cycles for new technology integration, and this in the light of new competitors entering the market with aggressive pricing. To succeed in this differentiation, European aviation needs to apply more resources to innovation, research and technology for quicker solutions and for adaptability to a rapidly changing environment.

To achieve the energy and environmental targets of Flightpath 2050 it is necessary to accelerate innovation, research and technology development with clear, effective and efficient supporting policies. These should embrace emerging cross-sectorial enablers such as digitalisation, big data and Industry 4.0. The level of support and investment must match the aspirations of the aviation sector as global leader, and ensure that it continues to generate a vast positive contribution to Europe. The mechanisms for this support need to be appropriate to the sector, building on successful current practice and recognising the full innovation value chain, the lead times of aeronautics technology maturation, and the scale and complexity of future technologies. Finally, Europe must recognise the level of external support being provided to the emerging competitive threats, and respond accordingly.

| ACTION AREA | 2050 TARGET STATE |
|---|---|
| **2.1** Increase competitiveness in product industrialisation | Industrialisation encompasses access to a full set of production data and capabilities of different production sites in order to simulate the best industrial choice proactively, starting at the early design and conception phases. |
| **2.2** Develop high-value manufacturing technologies | High-value manufacturing technologies represent an embedded digital thread within the integrated supply chain, facilitating a data-driven material conversion and manufacturing process. The technology is developed, validated and certified in a virtual workspace, enabling real-time changes in the physical manufacturing process. |
| **2.3** Embed design-for-excellence in the product lifecycle | The platform product development cycle, certification, and industrialisation operates on a single virtual development platform that reacts to, and embodies new architecture, systems and technology innovation in a fully autonomous environment. |
| **2.4** Secure continued and focused investment | Further innovative research, supported by continuous investment, is enabling aviation to meet the EU challenges of decarbonisation and digitalisation in an ever-changing, competitive and circular economy. |
| **2.5** Exploit the potential of operations and maintenance, repair and overhaul (MRO) | There is complete availability of data in worldwide overhaul networks. Supported by augmented and virtual reality techniques not only data, but whole competencies are available throughout the network. This enlarges the competitiveness of European aviation with greater flexibility and the ability to cope with unscheduled disturbances in flight operations and fleet management. |
| **2.6** Develop innovative and optimised testing | The full force of virtualisation technologies and cyber-physical systems is deployed to enable simulations that are as reliable as physical tests for most practical applications. |
| **2.7** Establish new business/enterprise models and initiatives | Physical, cyber and virtual business models are fully integrated to support the production of new concept aircraft to fulfil the Flightpath 2050 targets. |
| **2.8** Lead the development of standards | New configurations and new operations are based on dedicated new standards developed well in advance. |
| **2.9** Streamline certification | A fully-integrated multi-physics and multi-scale model of the complete airframe is coupled with aerodynamic and thermal models eliminating ground test rigs completely. A streamlined set of validation methods is supported by a regulatory framework for certification by simulation. |



# ACTION AREA 2.1

## Increase competitiveness in product industrialisation

Development of an aviation product involves many complex, interacting and critical activities and decisions. These must transform design concepts and analyses into an industrial product that is affordable, safe and sustainable in a competitive market.

**Effective industrialisation** is vital for European aviation. Included are specific and critical activities on qualification and certification, needed to fulfil customer and regulatory requirements. It is essential to implement design solutions with a solid industrial base that takes into account the very long life-cycles of aviation.

European aviation needs to build its competeveness across all horizontal industrialisation aspects: standardisation, specialisation, collaboration, automation and agility. These will benefit the aviation-specific pillars of product complexity, pressure on development targets and collaboration in the supply chain.

Aviation must manage **product complexity** that is increasing in a dramatic fashion, well beyond today's levels. Multidisciplinary and multi-objective optimisation processes are needed to achieve outstanding performance.

There is strong pressure to meet development targets with delivery on schedule, **within cost and respectful to the environment**. Modular solutions and standard practices are needed to speed up return on investment. These will use new technologies from different areas to reduce the financial demands of long-term research and development and promote faster testing.

**Effective collaboration** is needed with the supply chain for sub-assembly design and manufacturing. Aviation must forecast, analyse, share, manage and integrate the contributions of the whole supply chain in its long-term industrial scenarios. This must be done while continuously improving quality and safety, reducing costs and assuring data security.

**Digitalisation and big data**, supported by cybersecurity measures, will be key enablers, and these must be managed correctly. Critical information must be customised, classified and readily available for elaboration of production and product-support scenarios. It will be important to align with cross-cutting European initiatives for digitalisation and new factory and manufacturing paradigms.

OEMs must establish priorities to ensure they build products that provide a range of performance features to meet customer requirements. Collaboration with suppliers should be achieved by **sharing physical and digital resources**. Research is needed in the short- and mid-terms to simulate the value chain with data that include human, machine and industrial processes. Effective standardisation will be an important enabler in support of a modular approach.

Research for aviation industrialisation in a 2025 timeframe must focus on high-value technologies that enable the right choices to be made for productivity improvements. Innovation is needed for rate flexibility and decision support to cover the full life-cycle across the whole supply chain.

Disruptive industrialisation processes with full simulation of supply chain input and the impact of choices may be envisaged by 2035. This should be facilitated using building blocks from the digital economy.

By 2050, industrialisation should benefit from access to a full set of production data and capabilities across different sites in order to simulate the best industrial choices from early design and conception phases.

### Expected impact

Innovative choices in industrialisation concepts and management will provide the European aviation value chain a competitive advantage and global leadership. Future aviation products may be realised in a shorter time with quantitative information on risks and benefits. A minimal environmental footprint and optimal use of resources can be assured well in advance during critical industrial decision processes.

# ACTION AREA 2.2

## Develop high-value manufacturing technologies

The development of high-value manufacturing technologies is needed to secure the **competitiveness** of the European supply chain and affirm Europe's **global leadership** in high-efficiency manufacturing.

High-value manufacturing technologies are the processes, methods, and tools used for the creation of products and services. They may be described in three major themes.

First, **conventional manufacturing technologies**, which involve creation and finishing by mechanical and other means, and application of these processes for original equipment, in-service management, repair and end-of-life activities. Product and service verification and validation is predominantly assured through post-process techniques to minimise the cost of non-quality.

Secondly, **disruptive manufacturing technologies** involve generation from additive and subtractive methods currently not employed at industrial scale or used for prototyping only, including technology development, and manufacture of raw materials. Product verification and validation must be built into the process to ensure that "right first time" is achieved.

Finally, the digital, zero waste, and energy-neutral factory will use **data-driven manufacturing** systems to ensure high productivity, permit rapid new technology implementation, and enable product and rate flexibility through supply chain integration. This will facilitate innovative material formulation and manufacturing conversion, assembly and in-service support. The digitally-enabled factory should deliver zero-waste output from process consumables and product materials.

Specific aviation research is needed to focus on the material-to-product conversion processes that ensure safety, quality, fuel efficiency, environmental responsibility, cost-efficiency and flexibility. They must be embodied into the final outcome with the application of intelligent automation where economically viable.

It is critical to align with cross-cutting European initiatives addressing the digital economy and advanced manufacturing, where high-value technology convergence is a possibility.

Research in underpinning high-value technologies that enable productivity improvements and/or rate flexibility must be accelerated. Step change manufacturing technologies that could be implemented on incremental or new platforms to facilitate enhanced architectures through subtractive and additive processes, should be proven by 2025.

Disruptive manufacturing processes that deliver new architectural capabilities should establish standard industrial practice before 2035 in order to achieve the digitally enabled, low-energy and zero-waste factory.

By 2050 high-value manufacturing technologies should represent an embedded digital thread within the integrated supply chain, facilitating a data-driven material conversion and manufacturing process. The technology will be developed, validated and certified in a virtual workspace, enabling real-time changes in the physical manufacturing processes.

### Expected impact

The development of high-value manufacturing technology will secure the European supply chain through demonstrated global leadership in high-efficiency manufacturing capability. Future product aspirations will be realised through demonstrated capability to supply complex and multifunctional architectures, using intelligent automation within a digitally-enabled environment. A minimal environmental footprint, combined with high energy efficiency will ensure that industry increases economic contribution to the European Union, surpassing the 20% GDP industrial policy vision.

# ACTION AREA 2.3

## Embed design-for-excellence in the product lifecycle

Design-for-excellence is a key enabler for whole aircraft production and in-service optimisation. Design-for-excellence impacts material formulation, manufacturing conversion, and through-life services by embedding the philosophy throughout the product development pyramid.

Design-for-excellence is a combination of capabilities required to conceptualise, define, integrate, verify and validate complex aircraft architectures and systems through efficient use of material and manufacturing processes. It is sub-divided into three themes.

**Product:** Generation of a suite of verified and validated principles to optimise the architectures and systems to meet performance, fuel efficiency, operational needs, cost, and environmental needs. Topological optimisation ensures that the material chemistry can be optimised for the functional specification.

**Factory:** Evaluation of materials and manufacturing starting at the conceptual design stage. The outcome will consider the top-level aircraft and industrial requirements to best fit technology requirements with economic cost and rate objectives.

**Services:** Ensuring that consideration is given to in-service operational needs and flexibility throughout the product development pyramid, industrialisation phase and series production. This will ensure ease of interchangeability and minimise or eliminate maintenance and monitoring of architecture and system performance through data-driven services.

Knowledge must be exchanged with other high-value industrial sectors through collaborative initiatives, ensuring best practice is exploited throughout Europe.

It is imperative that design-for-excellence principles are embedded in ACARE, connecting with European initiatives on trans-sectorial topics such as digitalisation and future manufacturing. A knowledge-based engineering approach will maximise commercial impact and minimise the industrial footprint.

Research must ensure that principles addressed here are picked up in complementary programmes. Specifically, this will target next-generation platform developments where new materials, manufacturing processes, and digital enablers are envisaged.

Initial research needs to focus on product and industrial requirements for step-change and disruptive aircraft platforms. By 2025 the product development cycle should have embedded an integrated approach that meets operational targets and maximises the architecture and system performance through topological optimisation and multi-functional components.

By 2035, the product, factory and service elements should be integrated into open architecture platforms that enable full integration of the vertical and horizontal supply chain. By 2050, the platform product development cycle, certification, and industrialisation will be operating on a single virtual development platform that reacts to, and embodies, new architecture, systems and technology innovation in a fully autonomous environment.

### Expected impact

Sustained evolution of design for excellence will ultimately lead to a revolution in the product development cycle and through-life maintenance. The entire European supply chain needs to ensure its place at the leading edge of the development, and to maintain and grow its capability. Future high-value manufacturing aspirations will only be realised through an ability to first capture the principles of high-value design.

# ACTION AREA 2.4
## Secure continued and focused investment

Europe's aviation industry can maintain a critical mass of leading-edge capabilities and competitiveness through planned, continuous and focused investment in technology research and innovation. The timeframes for these investments are very long term, typically decades.

The focus should not just be on technology for aviation products, attention must also be given to manufacturing and operational technologies.

**Visibility and stability** in the support for long-term and large-scale private and public investment are needed. Efficient and dedicated research and technology innovation programmes must be organised within a stable, multiannual framework that can adapt to the changing landscape.

The research, technology and innovation pipeline is **filled on a rolling basis**, to ensure a continuous feed into demonstration, application and ultimately development. Targeted and specific interventions are needed to overcome market failure and fill the gap between the end of research and the start of product development.

Appropriate **funding instruments** must create sustained, stable and predictable research and technical development at manageable risk. They must cater for programmes of ten or twenty year's duration. Public-private partnerships and joint technology initiatives have proven to be efficient demonstrator-driven mechanisms. For example, SESAR and Clean Sky have delivered significant results and are recognised as best practice, inspiring other industrial sectors. There is a need for specific funding instruments to support basic and applied research up to technology demonstration.

To remain attractive and foster private investment, existing research and innovation programmes must be simplified and consolidated with **straightforward, lean rules and processes** suitable for all kinds of entities. The entire research and innovation chain must be supported at European level.

European priorities on digitalisation, energy and innovation are in line with ACARE 2050 recommendations. They should provide opportunities for further cross-fertilisation with other European technology platforms, while recognising aviation's specificities, development life cycle and intellectual property constraints.

The current Clean Sky 2 and SESAR 2020 programmes provide the necessary funding guarantees and stability to develop and introduce game-changing innovations at the aircraft platform level. Both airborne and ground-based demonstrators will be available by 2025. They will underpin innovation for next generations of aircraft in time for the next market window for replacement of the current fleet.

Disruptive industrial processes that deliver new architectural capabilities must be experimented before 2035 as part of future funding programmes.

By 2050, further innovative research, supported by continuous investment, will enable aviation to meet EU challenges of decarbonisation and digitalisation in an ever-changing, competitive and circular economy.

### Expected impact

Through continuous multi-annual, large research and innovation programmes, the European aviation industry and its supply chain will extend its industrial leadership while meeting the essential societal challenges of climate change and security. Further, high-skilled jobs will be created within a digitally-enabled environment.

# ACTION AREA 2.5

## Exploit the potential of operations and maintenance, repair and overhaul (MRO)

A significant value in European aviation is created during aircraft operations and through supporting services: maintenance, repair and overhaul (MRO).

Constantly increasing competition means that airlines must **maximise the operating time** of their fleet, reduce operating costs and minimise the number of unscheduled flight cancellations.

New technologies and data-driven services that will transform the business are now emerging; their exploitation will enable competitive European MRO capabilities. Products and services based on such innovations will ensure employment in crucial MRO areas and increase the competitiveness of European aviation. Research projects are therefore needed to develop and exploit these new approaches, fully integrating digitalisation.

Another essential component for the competitiveness of the European airline industry is **increased airport efficiency** and capacity for airlines and passengers. Implementation of the next generation of air traffic management systems, currently being developed in the SESAR program, is therefore vital.

Focus of this action area should be on developing **new services and products** that help airlines maximise their operating times, reduce operating costs and minimise the number of unplanned or unscheduled flight cancellations. These can be developed based on new technologies such as RPAS (remotely-piloted aircraft systems), new repair techniques (while taking into account REACH regulations), new materials (e.g. carbon-fiber-reinforced plastic) or data-driven services.

By 2025 first new technologies and innovative digital products should be available. By 2035 new aircraft will be generating massive quantities of data, much more than today. Developments must exploit this to generate services such as maintenance-on-condition and predictive maintenance based on big data analysis.

By 2050 worldwide overhaul networks should provide comprehensive availability of data. Supported by augmented- and virtual-reality techniques it should be possible to share this data to exploit competencies wherever they are available. This will improve the competitiveness of European aviation with increased flexibility and the ability to cope with unscheduled disturbances in flight operations and fleet management.

To achieve these goals adequate funding opportunities are needed to cover the whole field of digitalisation in aeronautics. These will ensure that Europe is the leader for digital ecosystems in support of innovation in aviation.

### Expected impact

The impact of new products and services to support airlines with digitalisation and high-technology MRO techniques will be enormous. Currently most innovation is directed at new aircraft to be produced in the coming years. However there is an opportunity to influence ACARE goals in the short term by targeting current operational fleets.

The competitiveness of European airlines will strongly depend on their ability to integrate future technologies in their daily business, and this will be done by way of innovative support services from MRO providers.

# ACTION AREA 2.6
## Develop innovative and optimised testing

Testing, at all levels up to flight trials, has always been an integral part of validation and verification to ensure the quality and safety of all aeronautical vehicles. Large-scale test activities are a critical part of research and development at high technical readiness levels since they validate technology integration in realistic operational scenarios.

Flight testing, in particular, is one of the most time-consuming and expensive parts of certification. Any underperformance at this stage is likely to result in significant production delays.

There is therefore a need for a better **optimisation of aviation test infrastructure** and related assets. This can be accomplished if the European aviation community better integrates its processes and fully exploits emerging technological enablers, including digitalisation.

A wider use of **distributed virtual simulation** and test, with early involvement of EASA in the research process, is of paramount importance and should be adopted as a means of compliance to regulations: more simulation and fewer tests.

Full-scale tests could be partially supplemented by **sub-scale or model-based certification** approaches, which will continue to grow in fidelity and reliability. This will be facilitated by the definition of global standards.

Sub-scale demonstrators will expand and become a pre-certification tool allowing, for example, reduced flight test on full-scale vehicles. Such testing facilities may replace or reduce certification tests for environmental and other aspects.

A broader use of wind tunnel facilities has the potential to replace some flight test activities. A solid European infrastructure of research and validation facilities thus needs to be maintained and further developed with new capabilities (see Challenge 5).

Advanced flight simulation will also support research and certification, acting as a high-fidelity substitute for flight – this is already the case for pilot training.

The overall objective must be to progress from the current patchwork approach, with local virtual testing and certification, to a **federated approach**. This must involve collaborative aircraft validation and verification, linking together all stakeholders. Ultimately this will enable new capabilities such as virtual hybrid testing: the seamless integration of simulation and physical test.

The advances described here could be developed in stages with, initially, incremental shifts followed later by transformational changes. As a first step, cheaper, modular test installations could prove a viable alternative to full-featured prototype demonstration by the year 2025.

In the 2035 timeframe the adoption of new practices and processes should lead to a significant reduction in global test hours. This will have a major impact on the time and cost to market.

By 2050 the full benefit of virtualisation technologies will unfold, enabling reliable simulations of complex cyber-physical systems which would not be practically feasible through other means.

### Expected impact

A smarter, more efficient mix of sub-scale test, ground test, virtual simulation and flight test will bring shorter innovation cycles within reach.

The benefits of new approaches to flight test will be broad; enhancing the competitiveness of European industry and meeting societal expectation for better, faster product innovation.

# ACTION AREA 2.7

## Establish new business/enterprise models and initiatives

The new world of connected products and services (Industry 4.0) provides an incentive for the aeronautics industry to adapt its business models. This should give rise to a number of developments and improvements.

There must be a **collaborative approach to innovation**, pooling the know-how of multiple stakeholders, including educational establishments, in order to accelerate the innovation process and provide the best possible response to customers' needs.

Innovative start-ups need to enter the process more easily, notably by opening digitalisation and virtual data to them, in line with an 'on-demand economy' business model.

Innovation vision must be combined with technology strategy (new ways of flying, the concept cabin, the concept plane) and services for connected products (machine-to-machine data, analytics, big data), to meet the evolving needs and expectations of customers as never before.

Focus needs to go beyond aircraft design to **include ground and air operations** to ensure that the expected growth in air travel will affect neither its safety nor sustainability.

Development and certification costs must be reduced with enhanced international certification processes for new technologies. These should make extensive use of advanced simulation tools and virtual design and certification capabilities.

An **updated regulatory framework** is needed, accompanied by corresponding funding instruments for future framework programmes. This will create a stable and predictable environment for research and technical development and innovation through grants and other financial instruments. These must take into account long lifecycles.

At the national level, investment in innovation should be rewarded by appropriate tax credits, allowing full deduction of staff costs in research and technology.

Entities such as the European Innovation Council, conceived as a complement to research and technology, should become the main point of reference for industry's innovation initiatives, and be a guide for SMEs.

Public policies and public procurement will be needed to influence supplier and consumer behavior, for example by encouraging the use of the next generation of aircraft and systems.

Finally, financial instruments and institutions will be needed to leverage the aviation sector's willingness to accelerate investment in new technology and promote fleet roll-over. The decommissioning of older aircraft following green life-cycle practices outlined in Challenge 3 should be facilitated through fiscal incentives.

In the 2025 timeframe focus should be on efficiency and resilience through collaborative approaches and steady provision of intellectual capacities and skills needed for innovation.

By 2035 there should be an approach that is increasingly complex, inclusive and strategic. This should develop ever-larger ecosystems and networks for testing new systems and ensuring sustainable use of resources.

2050 should target full integration of physical, cyber and virtual business models to produce new concept aircraft, fulfilling Flightpath 2050 targets.

### Expected impact

New business models will enable the aviation industry to keep pace with ever-faster innovation cycles at all levels, deliver environmentally-sustainable solutions for global needs and contribute to a better-connected world. The industry will take advantage of interdependencies between technologies and operations, and enable coordination with neighbouring fields of research.

# ACTION AREA 2.8
## Lead the development of standards

Standardisation plays an essential role in the aviation sector, covering many aspects from materials and processes through design and certification compliance to operations. It is essential to **develop standards early** in the innovation process to shorten time to market. There must be continued efforts to improve approaches to standardisation, building on existing projects.

The aviation sector should, in particular, benefit from the EC dedicated initiatives for European standardisation addressing digital single-market strategy and competitiveness through standardisation.

With increased **focus on the environmental impact of aviation**, the importance of new regulations concerning emissions and noise has increased. Europe must proactively participate in the related regulatory bodies with competent representation from all stakeholders.

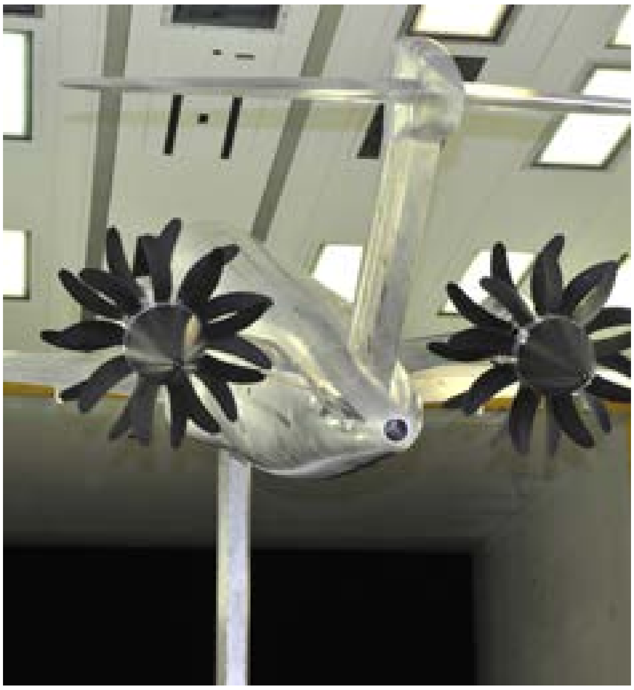
With regard to **new materials and processes**, the regulation on chemical products (REACH) is impacting the applicability of consolidated products, surface finishing and manufacturing processes and maintenance procedures. The use of composites and hybrid structures, as well as new techniques like additive manufacturing, requires the definition of suitable standards.

Innovative aircraft configurations will require new rules that include evolution in means of compliance.

Future developments **must take into account RPAS (remotely-piloted aircraft systems)**, whose increased presence needs adequate standards to allow them to safely integrate into airspace and operate alongside other airspace users.

New standards, **applicable in all flight segments**, are needed to ensure safety and efficiency of operations. They must cover air traffic management, extending to new avionics, data links, interoperability and procedures. Developments will embrace the requirements of Single European Sky and SESAR.

In summary, European stakeholders need specific initiatives to drive the development of suitable standards for new materials, processes and configurations, new requirements for environmental compliance and new operations. This will involve airworthiness regulators and international bodies. The early involvement of EASA is necessary.



To drive adaptation of future aircraft, new and revised standards on emissions and noise limits should be available by 2025.

By 2035 new aircraft and engine types should be ready for entry into service; these will need new certification standards and evolving criteria.

2050 may see radically new configurations and operations and these will again need new standards whose development must be started well in advance.

### Expected impact

In order to maintain the leadership and competitiveness of the European aeronautical sector it is essential to take a pro-active approach to standards and their evolution.

# ACTION AREA 2.9
## Streamline certification

Certification is a time- and cost-intensive process. Innovative approaches are needed to optimise it and thus reduce time to market.

Current processes do not fully exploit the range of **virtual tools** that are available. The use of tools for **automated analysis and design**, requirements tracking, data exchange and simulation, needs to be further enhanced. Virtual tools should increasingly become the principal means of demonstrating compliance. This also implies an evolution of full-scale testing requirements. Particular attention is needed to deal with derivative products that may need specific approaches.

A revised process will change the role of authorities such as EASA and modify the interactions between stakeholders. Better harmonisation of certification and acceptance processes between **military and civil authorities** at European level is necessary. Research projects should engage the authorities early to allow breakthrough technologies and innovations to be certified as quickly as possible, increasing their competitive edge.

Furthermore, new regulations on environmental compliance or standards for chemical products need to be addressed. This requires **upstream interaction with the regulators**, and this must be planned and properly resourced in the work programmes.

European stakeholders have already worked on the development of alternative methods of compliance; but further dedicated initiatives must be launched. These need to involve EASA directly in the virtual design process and in the definition of new standards applicable to new configurations, environmental compliance and new operations.

The dialogue with international bodies will be promoted though support to EASA with appropriate representation and data where requested.

By 2025 there should be increased use of validated simulation and ground testing infrastructures to provide evidence of compliance, reducing flight test requirement. This applies to testing at element, sub-element and component levels.

By 2035, in the medium-term, further improvements in simulation and ground testing approaches should be implemented. These include, for example, the modelling and prediction of icing effects for certification without recourse to flight trials. Structural validation, health-and-usage monitoring systems and on-condition maintenance should be further enhanced.

In the long-term, 2050 timeframe, a fully integrated multi-physics and multi-scale model of the complete aircraft including its engines and systems should be coupled with aerodynamic and thermal models, eliminating ground test rigs completely. A streamlined set of validation methods should be supported by a regulatory framework for certification by simulation.

Refer to Action areas 4.5 and 4.10 for certification requirements specifically for safety and security.

### Expected impact

The use of advanced methodologies to demonstrate compliance with safety and security requirements at component, product, system, and system-of-systems level, covering human, social and technical aspects, will contribute to higher efficiency, shorter time to market and lower costs for new products, services and operations.

# Timeline for Challenge 2: Maintaining and extending industrial leadership

2020 — 2035 — 2050

**2.1 Increase competitiveness in product industrialisation**

- Multidisciplinary and multi-objective optimisation processes to achieve outstanding performance in very complex products
- Modular solutions and standard practices by technologies from different areas to speed up in-service introduction and return on investment
- Digitalisation, big data and cyber-security measures to elaborate scenarios simulating value chain including human, machine and industrial processes

**2.2 Develop high value manufacturing technologies**

- Integration of bulk material and manufacturing conversion in resource efficient and topologically optimised architectures
- Digitally connected end to end vertical and horizontal supply chain
- Validation of net shape components optimised for product performance and maximum productivity

**2.3 Embed design for excellence in product lifecycle**

- Generation of integrated processes and tools that significantly reduce product development and industrialisation phases
- Digitally connected, open architecture supply chain integration across multiple vendor platforms for product realisation
- Design for X methodology applied to all design and industrialisation phases to optimise quality, cost and delivery

**2.4 Secure continued and focussed investment**

- Next generation multi-annual aviation R&I programmes, accelerating the innovation process, from idea generation up to demonstration phase.
- Attractive terms and conditions for innovation stakeholders to continue or engage in research activities in Europe
- Dedicated funding for both cross-cutting and disruptive technologies for new transport solutions and innovative business models

**2.5 Exploit the potential of MRO**

- New products and services for reducing MRO-expenses (predictive & business models)
- Optimised repair, test, and recycle technologies for innovative materials
- Infrastructure, knowledge and regulations for new digital services

| | |
| --- | --- |
| **2.6** Develop innovative and optimized Testing | Optimised combination of physical and virtual research infrastructures<br>Advances in computational power and modelling tools to transform predictive simulation into a robust test paradigm and lead to safety assurance in flight tests<br>Fostering global standards for innovative approaches to testing |
| **2.7** Establish new business/ enterprise models and initiatives | Demonstration of innovative new ways of connected air transport systems and new digital services<br>Agile business models with flexible funding mechanisms which support the full research and innovation value chain<br>Creation of an ecosystem which integrates the full research and innovation value chain from start-ups to industry leaders, across all transport modes |
| **2.8** Lead the development of standards | Interaction and involvement of EASA in new technology and standard assessment for future products<br>Active contribution to evolution of standards related to environmental targets for future aircraft compliance<br>Increased European involvement to influence worldwide standardisation bodies impacting the aviation sector |
| **2.9** Streamline certification | Development and qualification of new means of compliance with future certification requirements, including modelling & simulation<br>Interaction and involvement of EASA in new technology and configuration assessment for future products<br>Specific approaches validated for derivative aircraft or future aircraft approvals |

2020 2035 2050

# CHALLENGE 3

## Protecting the environment and the energy supply

Environmental protection is, and will continue to be, a key driver for aviation. The environmental goals in Flightpath 2050 recognise the need for aviation to accelerate its effort to reduce emissions that impact climate change, noise nuisance and air quality for the benefit of all citizens and to allow sustainable traffic growth.

The UN Framework Convention on Climate Change conference held in Paris in 2015 (COP 21) confirmed the aim to keep global temperature increase below 2°C compared with preindustrial levels. Aviation produces around 2% of all human-induced CO2 emissions. This share may seem low, but it risks increasing with traffic if insufficient measures are taken.

Aviation can reduce $CO_2$ emissions by improving the fuel efficiency of the entire system through technology, operations and infrastructure, but also by developing sustainable low-carbon aviation fuels.

Additional climate impacts result from nitrogen oxide (NOx) emissions and condensation trails that may lead to induced cirrus clouds.

Air quality, in particular regarding NOx and particulate matter, is also of increasing concern in and around airports.

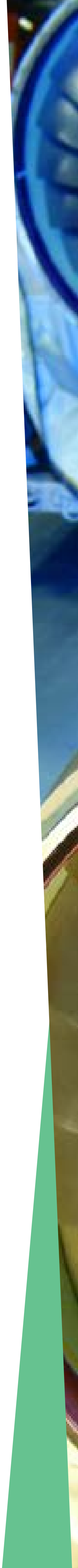
The 2050 noise reduction objective and negative effects of noise on human health require actions on vehicle and engine design, operational and infrastructure measures, and land-use planning. Better understanding of the effects of noise on health is essential.

Production, assembly and maintenance operations consume energy and raw materials, which also gives rise to emissions and waste. Full life-cycle analysis, from concept to end-of-life using circular economy methodologies, is needed.

Securing a sustainable energy supply to match the expansion of air transport will require joint efforts by the aviation and energy sectors.

This section describes the key actions that need to be taken in Europe to meet the mission level goals described in Flightpath 2050. ACARE monitors progress to ensure that they remain consistent with, and contribute to, the ATAG world fleet level goals as and when the technology is delivered in the short, medium and long terms.

To achieve the 2050 goals, step changes in aircraft configuration and operation (including alternative energy sources) will be required - currently envisaged evolutions will not be sufficient. Such disruptive change will have consequences for all stakeholders: manufacturers, airlines, airports, ANSPs and energy suppliers. The degree of change makes the future more uncertain but it also makes the technology programme and timing described in this section absolutely key if results are to be achieved by 2050. It is also essential that this technology roadmap and its implementation continue to receive support through government policy and that it remains a priority for European society.



| ACTION AREA | 2050 TARGET STATE |
|---|---|
| **3.1** Develop air vehicles of the future: evolutionary steps | These actions result in evolutionary aircraft developments that have driven progress in environmental performance towards FP2050 goals. Changes are introduced both into new aircraft and by retrofit across the civil aerospace fleet. |
| **3.2** Develop air vehicles of the future: revolutionary steps | New technologies have been developed and implemented that significantly surpass the capabilities of earlier-generation aircraft whilst improving on the high levels of reliability, safety and usability that customers demand. |
| **3.3** Increase resource use efficiency and recycling | Resources, materials and new processes are better focused on providing an aviation sector that is sustainable. End-of-service is characterised by high recyclability and reuse. |
| **3.4** Improve the environmental performance of air operations and traffic management | New operational practices are implemented resulting in optimised trajectories and reduced fuel-burn per flight in accordance with FP2050 goals. The FP2050 goal of emission-free taxiing is well on the way to being realised. |
| **3.5** Improve the airport environment | Air quality is improved and noise annoyance is reduced to acceptable levels. Airports are fully integrated and accepted by local communities. Intermodal transport connections are efficient and environmentally friendly. |
| **3.6** Provide the necessary quantity of affordable alternative energy | Sustainable alternative fuels are widely used contributing to a substantial reduction in aviation's impact on climate change. Disruptive alternatives for energy storage and supply are increasingly viable. |
| **3.7** Understand aviation's climate impact | There is a detailed, scientific understanding of the impact of aviation on the climate. This has enabled the introduction of sound, globally harmonized policies and regulations to support climate-friendly flight operations. |
| **3.8** Adapt to climate change | Impacts of climate change on aviation are well understood and steps have been taken to protect the efficient operations of air transport and the integrity of its infrastructures. |
| **3.9** Develop incentives and regulations | There exists a comprehensive framework of policy, regulation and incentive to ensure the implementation of new technologies and operations destined to reduce the impact of aviation on climate change. |

# ACTION AREA 3.1

## Develop air vehicles of the future: evolutionary steps

Current aircraft configurations have evolved with a century of innovation and development. Revolutionary changes in aircraft design have been accompanied by evolutionary developments and these have together resulted in highly efficient, safe aircraft. **Further evolutionary change is essential** in order to achieve the Flightpath 2050 environmental goals.

In the mid-term, incremental improvements will come **either from new-built aircraft or from upgrades and retrofits to existing fleets**, for example new engine options or other system changes. In the long term more radical concepts and technologies will be necessary – these are described in the next action area.

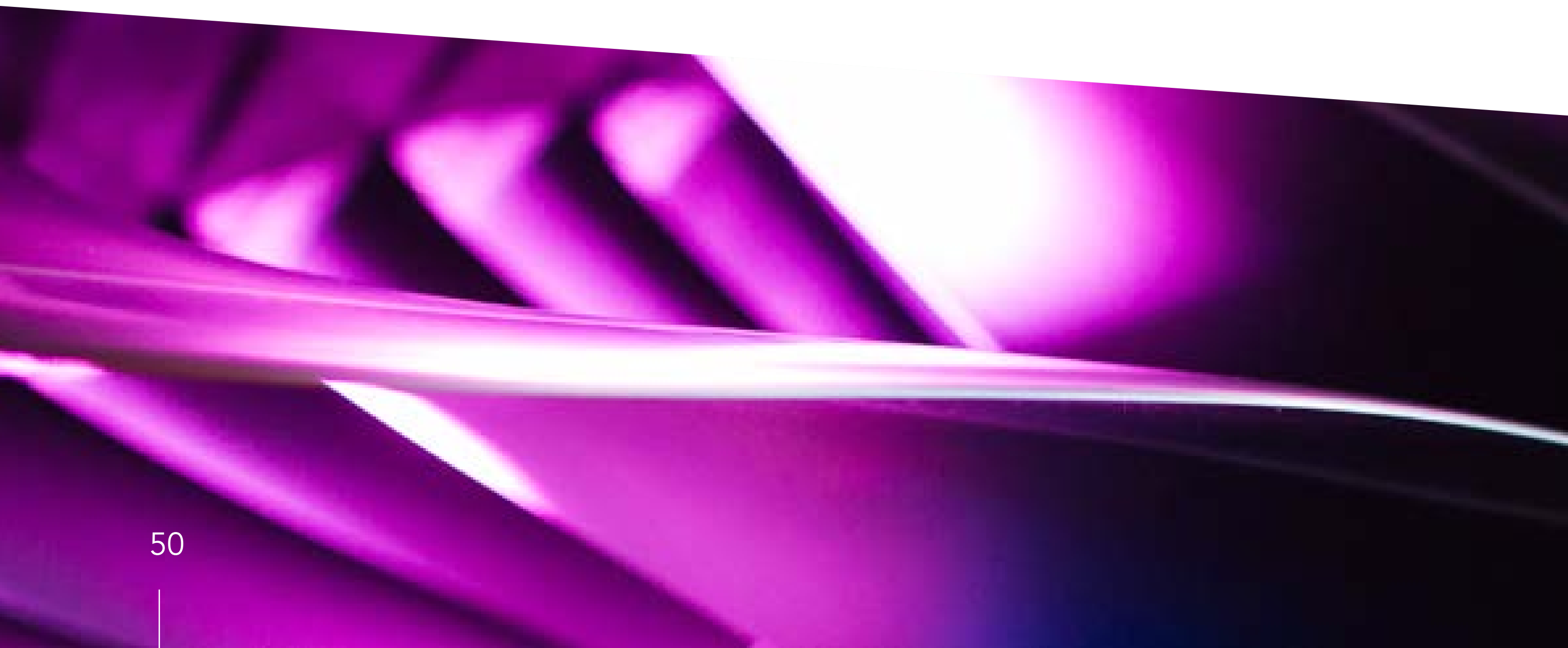
The environmental footprint of aviation is also influenced by **through-life support**, so improvements in fleet data management and on-board health monitoring are needed. Further benefit should come from improved repair or re-manufacturing techniques (with composites and alloys containing rare or strategic elements) and new additive manufacturing processes.

Design and validation needs to be supported by better computer-based tools, reducing reliance on physical hardware and testing. This will speed up the introduction of new, environmentally-sensitive technology in a safe and reliable manner. In general, measures must be developed to ensure that new **technology is introduced as early as possible** to maximise benefits in emission and noise reduction.

**Airframes** (including cabin interiors) must bring benefit from increased innovation in lightweight materials, including composites. Their use will require new approaches to design and manufacturing, with multifunctional materials and structures for weight-saving, reduced manufacturing cost and increased production rate. Improved aircraft performance for low- and high-speed phases should be achieved with innovative aerodynamics including laminar flow and aero-elasticity control. Design for end-to-end performance improvement must be achieved with multidisciplinary approaches such as multi-criteria optimisation and digital model based engineering.

**Propulsion** developments need to target higher thermal and propulsive efficiency. As with airframes, materials will play a significant role with new lightweight structures and high-temperature materials for engine cores. Awareness of adverse health effects of NOx and combustion particulates, especially for local airport air quality, must drive research and innovation in combustion systems. Alternative fuels such as high-blend drop-in kerosene will play an important role in overall $CO_2$ reduction (see Action area 3.6), and their effect on engines and aircraft systems must be mastered.

Close collaboration between airframe and engine manufacturers will be needed to install advanced, possibly even larger , more complex propulsion systems onto aircraft. In this respect ultrahigh bypass ratio engines of all types will present new challenges. Moreover, these will use high power, high speed gearbox components requiring new technology for their development and introduction.



**On-board aircraft systems** and equipment must support a more-electric aircraft. This particularly concerns power generation, from main engine or auxiliary unit, distribution and conversion. Alternative on-board energy applications such as all-electric bleed or fuel cells have already been demonstrated. However, research must target system capabilities, weight and cost reductions and improved reliability. Noise and weight reductions can also be achieved in on-board systems such as landing gear, high-lift devices and actuators and low-noise, low-drag nacelles. These key systems will face specific challenges with the installation of ultrahigh bypass ratio engines; research is needed to balance the competing needs.

Systems to allow taxiing without the use of aircraft engines have been proposed for existing aircraft. Their efficiency must be further improved for new aircraft in order to fulfil the Flightpath 2050 goal of emission-free taxiing.

On-board aircraft systems must be capable of supporting new operations and air traffic management concepts for reduction of emissions and noise (see Action area 3.4). This includes navigation systems with improved accuracy and integrity, new atmospheric sensors and connectivity for flexible, optimised trajectories. Aircraft cockpits will need automation and flight crew support to implement these changes.

Research is needed to develop aircraft systems that are not subject to obsolescence and are future-proof to accommodate functional and operational changes for improved safety and efficiency.

Further attention must be given to local noise effects around airports, heliports and vertiports, with specific measures to reduce tones, frequencies and magnitudes that are considered annoying.

### Expected impact

Research and innovation for evolutionary aircraft development described in this action area will drive progress in environmental performance to be on track towards the FP2050 goals. Changes will be introduced in new aircraft or by retrofit into the growing civil aerospace fleet.

# ACTION AREA 3.2

## Develop air vehicles of the future: revolutionary steps

To achieve the environmental goals defined for 2050 will require a step change in aircraft configuration and on-board system capabilities. Focus will remain on $CO_2$, NOx and noise, but the effect of noise and aircraft emissions, including particulates, on local communities will have greater importance.

Future, revolutionary changes in aircraft design, propulsion units and on-board systems will need to prove their worth compared with the evolutionary developments described in Action area 3.1. However, their introduction is essential for progress to carbon-neutral air vehicles. A number of enablers can be identified for achievement of this ambitious goal.

The first enabler is **radical new design** for airframe, cabin, propulsion and on-board systems to bring step changes in capability over the full mission of the aircraft.

**New energy sources** will be needed including electric and hybrid, alternative fuels or renewables.

There must be a step change in **capabilities or modes of operation** to meet future global passenger volumes and locations.

**Health monitoring** must apply to all elements, airframes, cabin interiors, engines and systems. They must include prognostics and connectivity for system safety, availability and reliability.

The use of **whole-aircraft systems engineering** that incorporates airframe, propulsion and systems will improve efficiency and reduce emissions through greater systems integration and optimisation.

Finally, developments must target **near-total use of recycled materials** and the ability to remanufacture and recycle once typical duty cycles have been completed.

These changes are explicitly categorised as 'revolutionary', and require substantial research efforts together with effective engagement from certifying authorities. There must also be provision for integration of new air vehicles into existing infrastructure, for example with adapted airports to support new energy supplies.

To achieve new **airframe** configurations, novel structures will be required along with new materials, manufacturing techniques and design methods. These are not yet fully understood, so research must continue.

Further studies are needed for more radical offerings such as compound helicopters, tilt-rotors, high propulsive efficiency vehicles with distributed propulsion, and blended- or braced-wing structures. Integration of propulsive units for optimum airframe configurations will generate challenges, but may bring significant benefits. Cabin design may need to evolve significantly to accommodate new airframe structures and configurations. Finally, efficient, reliable, safe operations of these aircraft must be developed.

For **propulsion** systems it is necessary that alternative sources of energy become feasible for aviation. As described in Action area 3.6, these alternative sources will include non-kerosene, renewable energy such as electrical and hybrid power for both thrust generation and on-board functions. On-board storage of non-kerosene energy de-

mands a huge research effort, especially given the weight-, volume- and safety-critical nature of aviation.

Key areas of research will focus on energy/power density, recharge/discharge rates, re-use capability, materials (such as avoiding rare elements) and heat management. One or two orders of magnitude increase in capability will be needed. Where traditional carbon-based fuel continues to be used, engines may have radically different configurations with changes to the overall energy release cycle.

The introduction of more electric power for non-propulsive and propulsive energy will imply radical redesign of aircraft architectures and many energy sub-systems. Preliminary architecture studies are required now using integrated, multi-domain modelling tools. Systems and equipment to support these future architectures will need to manage very high levels of energy and heat, with high safety and reliability and low weight.

Radical new aircraft configurations will also require new designs for landing gear and engine nacelles, pods and installations. These will also help meet the noise challenge.

Fundamental and demonstrable research in the areas described above is needed to achieve Flightpath 2050's long-term environmental goals. Beyond 2035 air vehicle design will require more radical solutions than can be provided by incremental and evolutionary change. Research to enable this radical shift is ongoing but requires more specific focus and support.

### Expected impact

New technologies will significantly surpass the capabilities of today's aircraft whilst maintaining or improving on the high levels of reliability, safety and usability that customers demand.

# ACTION AREA 3.3

## Increase resource use efficiency and recycling

In addition to the Flightpath 2050 objective "Air vehicles are designed and manufactured to be recyclable", the aviation sector must align with the EU strategy to reduce landfill by means of maximum resource recovery and reuse of materials. This will happen either by optimising existing production processes or developing new ones.

In an **eco-design** approach, the integration of novel innovations in materials and processes are investigated, supported by **life-cycle assessment**. This contributes to lower energy and resource demand, increased component life and better reuse and recyclability for future, more sustainable aeronautical product designs.

Applying **design-for-environment and design-for-recycling** methods to aircraft will lead to reduced dismantling costs and higher recovery rates for the materials. This includes the development of easily-recyclable polymers such as thermoplastics or bio-derived and naturally biodegradable polymers for structural applications.

While materials from production, maintenance, repair and operations may be readily reusable, materials from **end-of-life aircraft** might need to find other applications since the long lifespan of an aircraft may render them altered or obsolete, or significantly increase certification requirements. For some materials, such as recycled carbon fibre, finding applications may be problematic due to small quantities or high recycling costs. The search for new applications needs to be intensified and to be included in the design process.

Recycling and reuse are part of the full life-cycle of materials and products (ISO 14040). The quantity and quality of recyclable or reusable scrap, from semi-finished products or final parts, must be identified. Recycling needs a stepwise **scrap-management process**.

Use cases for recycled materials will need to be regularly revised and best practice regularly communicated to recycling companies. These best practices should cover areas including: dismantling, differentiating serviceable parts or modules which can be reused from recyclable parts and pollutants, identifying hazardous materials to be removed before recycling, and improving traceability of parts.

**Smart logistics** and networks to collect residues from production, maintenance, repair and operations (for example by reverse logistics) and end-of-life will reduce recycling costs and generate new business models.

The current aircraft recycling business is highly dependent on the value of extracted parts and volatile raw material prices. Lack of regulation causes a direct dependency of recycling rate on market prices: low market prices lead to low recycling rates. To support EU strategy it is necessary to estimate recycling rates that are needed to ensure the sustainability of certain rare or strategic materials.

A policy for the end-of-life of products at all levels of the supply chain could lead to different product designs. Finally, a proactive recycling policy is needed to accelerate safe elimination of hazardous substances.

### Expected impact

The proposed actions will ensure the development of sustainable aeronautical products through increased recyclability and reuse at the end of service life to ensure better use of resources, materials and processes.

# ACTION AREA 3.4

## Improve the environmental performance of air operations and traffic management

The short-term development of air operations and air traffic management (ATM) will be defined by SESAR and Clean Sky, an integral part of both is the improved environmental performance of air-traffic operations. The requirement for sustainable growth and decarbonisation will be supported both by the adoption of **best practices** and by the development of **standards** for aircraft operations and air traffic services.

New operational concepts based on multiple aircraft/fleet interactions in a large air traffic service approach will be needed to enable process optimisation, **jointly implemented by ATM and operators**, with the air-travel segment seen as part of a multimodal door-to-door journey. Research is needed for a better understanding and assessment of environmental and socio-economic impacts to enable strategic and tactical real-time adjustment of operating practices to minimise these. Fleet operations must be monitored in a way that provides customers with visibility of available options and their associated impacts. This will give them the ability to actively participate in greening their travel itineraries (described in Challenge 1).

Improvements to air operations and traffic management should deliver significant environmental benefits. The individual optimisation of each aircraft operation will reduce fuel usage (and hence $CO_2$ emissions) and perceived noise. **Every phase of a flight, and the flight as a whole**, needs to be optimised for environmental efficiency in the new ATM context developed by SESAR. 4-D trajectory management should be standard.

The impact of winds and any adverse weather conditions need to be fully accounted for in flight planning and in real-time, using data made available through system-wide information management.

The increasing availability and use of **remotely-piloted aircraft systems (RPAS)** must be carefully managed in order not to create problems for the safe execution of ATM. However, their impact on the environmental well-being of the population is not very strong and could be mitigated predominantly through regulation rather than through research.

In the medium-term, flexible flight-management systems, accurate satellite navigation systems and new atmospheric sensors should enable **trajectories to be optimised**, and fuel-burn minimised. This must be done with deployment of new operational concepts such as free routing and free flight. In addition, aircraft networking and system-wide information management should allow, among other things, the sharing of situational awareness, and self-spacing to optimise runway capacity.

**RPAS will need to be seamlessly integrated** into the ATM system using robust sense-and avoid technologies that prevent any unnecessary increase in fuel-burn by traditional air traffic.

Research is needed to better understand **contrail physics** to allow robust decision-making on the trade-off between contrail avoidance and $CO_2$ reduction. This should enable their impacts to be minimised through dynamic flight planning.

More advanced concepts, such as formation flight, must be researched for the medium to long-term to give further improvements in fuel efficiency. Additional gains should also be delivered by the identification and assessment of environmental benefits at the aggregated multi-trip level, leading to flexible/adaptive schedules from operators. Air-trip optimisation could then be extended to the global transport network, including ground transport.

### Expected impact

The operational gains resulting from these research activities will induce a reduction of between 250kg and 500kg of fuel (800kg to 1600kg of $CO_2$) per flight - 5-10% of the total - as a major contribution towards the Flightpath 2050 goal of a 75% reduction. This includes a 30% reduction in taxiing fuel-burn per flight due to advanced taxiing operations in pursuit of the goal of emission-free taxiing.

# ACTION AREA 3.5
## Improve the airport environment

Airport development must be sustainable in a way that contributes to an improvement of the health environment **within its boundaries and in surrounding communities**. This includes the impact of pollutant emissions on air quality, noise nuisance and other environmental concerns such as water pollution and $CO_2$ footprint.

The main pollutants affecting air quality at airports are nitrogen oxides (NOx), particulate matter, and to a lesser extent, carbon monoxide (CO) and unburned hydrocarbons. ICAO certification standards apply to all these emissions; the adoption of the first particulate matter standard in 2016 highlights the growing attention given to this pollutant. Further improvement of scientific understanding of its effects on health is needed.

Pollutant emissions are mainly determined by **aircraft engines**, and to a lesser extent **auxiliary power units**. Further measures, which can directly be influenced by the airport, address aircraft **ground operations**, ground handling and terminal operations. Emission-free taxiing could become an integral part of airport operations. **Airport access**, whether by individual or public transport, surface or underground, should be improved for reduced environmental footprint.

Assessment of air quality impact at or near airports must be based on accurate measures or prediction of air vehicle emissions combined with sound atmospheric transport models. This needs to be complemented by direct measurement of pollutant concentrations at and around airports.

**Noise nuisance mitigation** must form part of airport expansion plans. The principle of ICAO's balanced approach for reducing noise annoyance must be maintained. This means noise reduction at source, land-use planning and management, operational procedures for noise abatement and aircraft operating restrictions as a last resort. This must be managed in collaboration with communities around the airport.

The increased role of the **rotorcraft sector**, with improved helicopters and advanced vehicle configurations such as tilt-rotors and compound architectures, may lead to an increase of heliports and vertiports in both densely and sparsely populated areas. In addition, en-route noise from future aircraft architectures and from new vehicle types flying low altitude routes needs to be managed effectively.

Assessment of the airport's environmental impact should be supported by a fully-integrated European environmental-impacts tool suite.

More energy-efficient airports must be achieved by operational and infrastructure measures relying, in particular, on greater use of renewable energy to achieve a low carbon footprint. This covers the whole energy chain of production, distribution, conversion, supply, storage and consumption. Fixed power, green land transport vehicles should be fueled with such low-carbon energy.

The use of **environmentally-friendly chemicals** (e.g. for aircraft de-icing) and sustainable approaches to water use needs to be generalized at airports. **Maintenance and disposal** operations must also integrate sustainability criteria.

Land-use around airports needs to be planned and developed for the long term. This must recognise the benefits and penalties of such proximity, with the airport **fully integrated into its neighbourhood** and full partnership between transport operators and local authorities. There must be full understanding of the level of nuisance, annoyance, sleep disturbance, health effects etc. of emissions, noise and other aviation impacts.

Minimising these will give neighbours a more positive image of aviation and its supporting infrastructure. This must be supported by a positive and transparent communication strategy that should include awareness of technological progress.

## Expected impact

Specific research for the airport environment will permit significant improvement in air quality and reduction of noise annoyance at European airports, with the most appropriate solutions for these key environmental concerns.

# ACTION AREA 3.6

## Provide the necessary quantity of affordable alternative energy

Large-scale use of renewable energy and energy carriers will be instrumental in reducing aviation's environmental footprint to meet the sector's ambitious targets for greenhouse gas emissions.

Disruptive solutions with near-zero emissions, for example electric flying based on renewable electricity, should be investigated for long-term application. However, **sustainable drop-in alternative fuels** are seen as a promising way of reducing the carbon footprint of aviation in the short and medium terms. This will require extensive introduction of renewable fuels with the highest potential to reduce greenhouse gas emissions.

Aviation needs to increase its use of sustainable alternative fuels to a substantial percentage in the medium term to contribute to carbon-neutral growth from 2020 onwards. Europe's long-term goal, as stated in the EU 2010 Transport White Paper, is for aviation to use minimum 40% sustainable alternative fuels in Europe by 2050. To meet fully the Air Transport Action Group global target of halving $CO_2$ emissions in 2050 compared to 2005, the vast majority of jet fuel needs to have strongly reduced lifecycle greenhouse gas emissions compared with conventional jet fuel.

Sustainable alternative fuels can be produced **from various sources** such as biomass streams, including waste and residues from agriculture and forestry, or from industrial and domestic waste, including industrial fumes. Processes are being developed to produce alternative fuels from renewable energy and $CO_2$ from industrial sources or from the atmosphere, with, for example **power-to-liquid** and **solar-to-liquid** technologies. Ideally, only renewable carbon sources will be used in the future.

Ensuring sustainability of air transport is a prerequisite for growth in the aviation industry, so there is strong impetus for the development of renewable fuels and energies. Research and innovation must target effective greenhouse gas reduction, but also other environmental, social and economic sustainability. A **global view of sustainability criteria** is needed to support worldwide deployment of renewable aviation fuels, guaranteeing high sustainability while avoiding competitive distortion.

Despite substantial interest and efforts, alternative aviation fuels have not yet been implemented on a significant scale. The main obstacle for commercial deployment are the **higher costs** associated with their production and frequently-changing regulatory frameworks. An integrated transport and energy policy is needed incorporating a stable set of financial and legislative instruments. This will foster research and development, encourage investment in production facilities and ensure that sustainable fuels are competitive alongside conventional alternatives. Policy must be based on a detailed understanding of sustainably-available quantities of feedstock and renewable energy in Europe.

A **level playing field** is required between aviation and other transport modes and industrial sectors. Priority in the availability of drop-in fuels must be given to sectors such as aviation that have no obvious alternative sustainable energy sources.

Intensive research and development efforts are required to mature high-potential technologies for affordable large-scale implementation – this must be supported by large-scale demonstrator projects. **Close collaboration is needed between aviation and energy sectors** to ensure that aviation-specific needs are taken into account. A coherent strategy covering all these sectors is required to concentrate efforts on technologies and value chains that offer the highest potential benefits at acceptable risks.

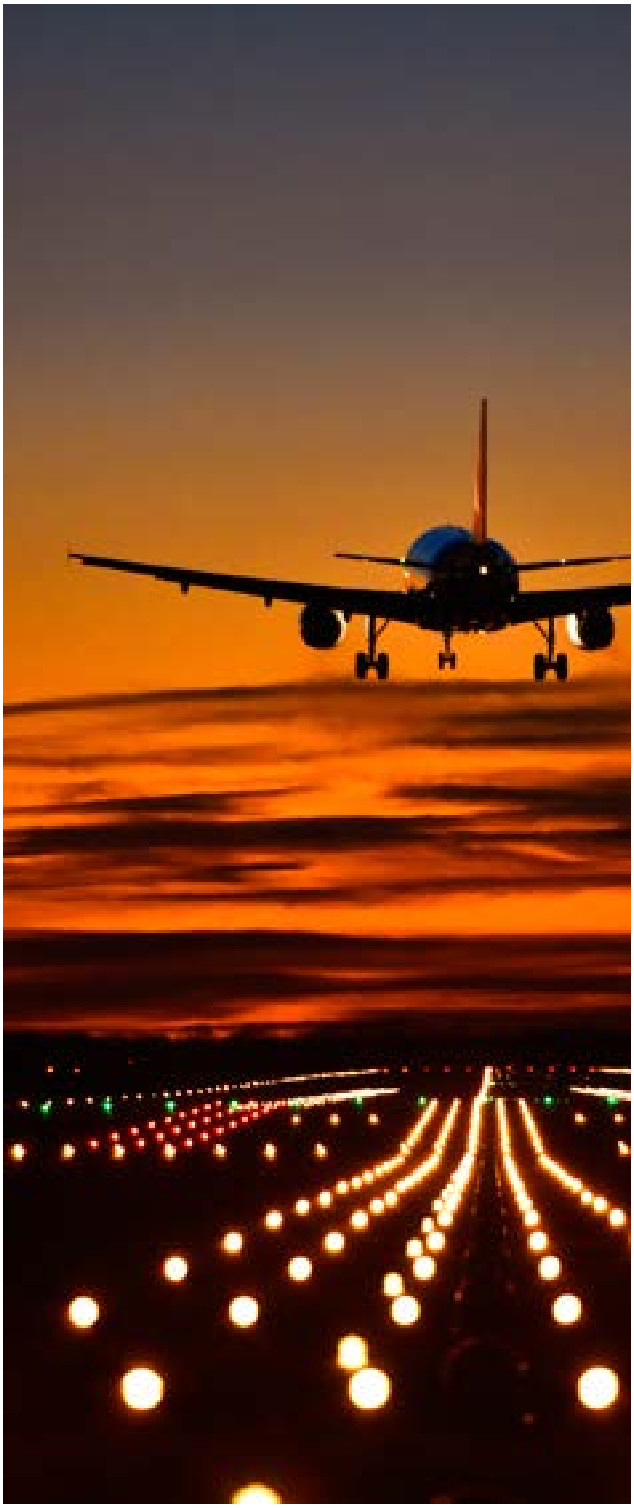
Specific research objectives include minimising greenhouse gas emissions over the full lifecycle; high conversion efficiency and low input demand (water, energy, …); minimal production costs without compromising environmental performance; scalability, using several types of feedstock and feedstock-flexible processes and minimizing risk of negative social or environmental effects such as soil pollution or depletion and land use change.

Efficient processes for **rapid, cost-effective technical approval** of new fuels are needed. These processes must be based on an in-depth understanding of the relation between chemical fuel composition and properties: storage, combustion, emissions, effect on engine and aircraft fuel systems as well as the distribution system. Such knowledge will also be used to optimize formulation of renewable fuels towards improved combustion properties and reduced pollutant emissions such as particulate matter. Note that alternative aviation fuels are also expected to have a beneficial effect on climate due to reduced particulate matter emissions and related contrail formation. Improved understanding of this effect is necessary.

For the long term, potential environmental **benefits of disruptive (non-drop-in) technologies for energy storage and supply** must be explored with an end-to-end perspective. In most cases these require considerable modification of aircraft configurations and therefore fall within the scope of revolutionary air vehicles described in Action area 3.2. Such technologies could include, inter alia, gaseous or liquid non-kerosene fuels as well as electric energy. Their development should benefit from trends towards enhanced use of renewable energies in other industries.

## Expected impact

Research and technology results on alternative aviation fuels, in cooperation with the renewable sector and backed by a favourable policy framework, will enable the large-scale deployment of sustainable alternative fuels, which will contribute to a substantial reduction of aviation's climate impact.



# ACTION AREA 3.7
## Understand aviation's climate impact

Full **scientific understanding** of the impact of aviation on the atmosphere supported by appropriate **measurement capabilities** is necessary for informed decision-making. This will allow aircraft operators, manufacturers and air navigation service providers to choose the best options to mitigate air transport's environmental impact. It will also enable the establishment of **global environmental standards** based on agreed scientific principles.

Detailed knowledge and understanding of aircraft emissions beyond $CO_2$ including NOx, particulate matter and contrail-forming water vapour, must be acquired. This must be based on accepted measurement techniques that fully characterise **engine exhaust emissions** on the ground, in altitude test cells and in flight. In support of this, computational fluid dynamics models must be available to predict the effects on exhaust emissions of new engine technologies and **different fuel compositions**.

The capability to monitor the air vehicle environment in flight (around and behind) should allow measurement of pollutant concentrations in the atmosphere at the global scale, in a particular flight corridor or behind specific flights. Further, the capability must be developed to monitor the effect of aviation on the **extent and optical properties of clouds**, as well as detailed atmospheric conditions along proposed flight paths.

For a well-balanced approach for reducing aviation's total climate impact, we must significantly improve the understanding of both **$CO_2$ and non-$CO_2$** emissions' impact, and of the physical processes of interactions between the aircraft and the atmosphere. Scientific tools must be developed and adapted to analyse the current and future impact of air transport. Atmospheric and climate models at different geographic and time scales must be adapted or developed, as well as specific measurement techniques for **model validation**. Appropriate and representative metrics will bring to the aviation sector a **single framework** for expressing, quantifying and managing long-term and shorter-term impacts.

**Numerical simulations and physical models** must be developed to describe accurately the processes that affect aircraft engine emissions in the atmosphere, and the whole range of aviation-induced effects on different time and space scales. The role of NOx, contrails and induced cirrus clouds must be modelled with high accuracy. Models should take into account atmospheric feedback due to the aviation emission on different time and geographic scales. Tools and algorithms should be available to **exchange data easily between models** operating on different scales and to provide the flexibility to import data from new sources when they become available. Eventually, the new tools will allow each individual flight's contribution to climate change to be quantified using appropriate metrics.

Infrastructure and processes must be in place to enhance **environmental impact monitoring**. This should include specific instruments such as sensors carried on air vehicles as well as information on global atmospheric conditions collected by earth observation and prediction systems. The system must be able to provide precise environmental information to the advanced air traffic management system.

Traditional flight optimisation is based on minimum flight time or direct operating costs. The developments described here will allow climate change to be incorporated into **multi-criteria flight optimisation** that combines climate impact with operating time and cost. Eventually, airframes will be optimised for flight trajectories with minimal climate impact.

### Expected impact

Improvements in scientific understanding of aviation climate impact will enable the introduction of scientifically-founded and globally-harmonized policy and regulations to support climate-friendly flight operations, and will highlight the mitigation priorities for manufacturers.

# ACTION AREA 3.8
## Adapt to climate change

It is essential that efforts to mitigate the sector's contribution to anthropogenic climate change are continued and augmented. However, there is now growing recognition that measures may also be required to **adapt and build resilience** to the possible effects of climate change.

The potential impacts of climate change include both an **increase in the frequency and intensity of weather events** that may be associated with disruptive impacts, and **changes to baseline conditions** such as average temperature and precipitation, wind patterns and sea-level rise. These can affect air operations, traffic management and infrastructure, and necessitate adapting the air transport system to be resilient to future climate.

However, although the effects are broadly identified at a qualitative level, further research is required to **quantify potential impacts**, and this must involve increased collaboration with the scientific community. To support robust decision-making and cost-benefit analyses, it is important that techniques are also developed to evaluate the probability of occurrence of these potential impacts.

Action to adapt and build resilience is required at both local and network level. Measures may include adaptation of **infrastructure** and the introduction or augmentation of **operational provisions** to better manage disruption. Win-win measures which can address other challenges, such as capacity, whilst also building climate resilience may bring particular benefits. Development of risk-assessment and decision-making tools which account for flexibility and uncertainty will also be required.

Climate adaptation must be addressed **in cooperation with other transport modes** and relevant sectors such as energy and communication: development of methodologies to identify cascading effects will be required. It is also important to identify potential design trade-offs, and ascertain where research efforts may need to be increased. For example, climate change may lead to **harsher operating conditions** for engines with ice, hail or sand ingestion. This may make the design of lighter, more fuel-efficient engines more challenging and require solutions which meet design requirements in a more resilient way. Changes in operating conditions may lead to changes in **certification rules**, so sound research is needed to ensure that these are built on robust information.

In general, it is important to understand how a future lower-carbon aviation system might look like, and adapt for that, rather than assuming the system will remain as today's. For this, co-ordination between disciplines and stakeholders will be key.

Continued research is then needed to improve identification and understanding of the potential impacts and associated adaptation and resilience measures across the sector, and their trade-offs and interdependencies. It is necessary to develop risk assessment methodologies and metrics to measure resilience and assess effectiveness of actions. These are ongoing actions that should be constantly aligned with evolving scientific knowledge of the impact of climate change and implementation of resilience measures.

### Expected impact

The understanding of climate change risks to aviation, and implementation of measures to tackle them, are essential to facilitate safe and efficient operation of air transport and to protect its infrastructure in the face of increasing impacts.

# ACTION AREA 3.9
## Develop incentives and regulations

Environmental impacts are highly regulated at local, national, EU and international levels. Aviation as a global business has a strong need for **internationally harmonised rules**, in terms of both design and operational requirements.

Environmental standards, such as those established by ICAO for noise and emissions, have accelerated the development of new technologies. Aircraft and engine manufacturers compete with each other trying to exceed certification levels by the best possible margins. Radically new technologies such as open rotors and electric aircraft will probably require **adaptation of existing standards**.

To complement technical environmental standards and measures, the 39th ICAO Assembly agreed on a global-market based measure for international aviation. The scheme established by ICAO is a global offsetting mechanism, under which aircraft operators will be required to offset the sector's growth in $CO_2$ emissions above 2020 levels.

To achieve Flightpath 2050 environmental goals it is important **that legislative, regulatory and policy frameworks** at EU, national and local (airport) levels encourage the adoption of new environmentally-friendly technologies instead of creating obstacles to their deployment or operation. Assessing the economic impact of **different combinations of controls**, incentives and instruments is crucial. Risks and unintended consequences must be identified.

While actual research and technology efforts in aviation are well supported in Europe, incentives and legislative support encouraging the implementation of innovative technologies are often lacking for the gap between development and deployment - the "valley of death". The most prominent example of this in green aviation technologies is the implementation of sustainable alternative fuels. Today, these are expensive niche products and are therefore purchased in low quantities only. This does not help producers and investors reduce their risks. **Carefully selected policy instruments are needed to foster demand** and ensure large-scale production.

Environmental regulations and policy instruments applied to aviation must be built on effective **knowledge sharing with other sectors**, while recognising aviation specificities.

The (ICAO-based) certification process for new technologies needs to be enhanced to decrease its cost and duration without degrading its efficiency. It is also necessary to adapt environmental certification rules for new configurations and systems such as all-/more-electric and hybrid technologies.

A policy framework supporting renewable fuel production and use is needed to make currently expensive renewable fuels economically competitive. In addition, the ASTM-based certification process for new alternative fuel pathways should be enhanced.

Additional research is needed in some areas of broader environmental policy, such as circular economy, to identify how aviation is specifically affected.

It is impossible to set a roadmap for planning regulations and incentives for a 2035 or even 2050 timeframe. Nevertheless, **legislative stability is a vital prerequisite** to encourage investments in new technologies. Moreover, if the certification and deployment of new technologies requires adaptation of existing regulations, sufficient time must be planned for the rulemaking process.

### Expected impact

The implementation of new technologies to reduce the environmental impact of aviation, including a transition to more renewable energies, will only work if embedded in a holistic transport and energy policy framework. Research in this field will deliver these incentives and regulations to support the FP2050 goals.

# Timeline for Challenge 3: Protecting the environment and the energy supply

2020 | 2035 | 2050

**3.1** Develop air vehicles of the future: evolutionary steps

- Fuel-optimised conventional aircraft, engines and system technologies
- Noise-optimised conventional aircraft, engines and system technologies
- Lean combustion engine
- Multifunctional, highly capable materials

**3.2** Develop air vehicles of the future: revolutionary steps

- Fully electrical on-board energy
- Concept studies for electric and hybrid propulsion
- Radical and optimised aircraft configurations with adapted on-board and propulsion systems, achieving set environmental targets

**3.3** Increase resource use efficiency and recycling

- Eco design guidance including end-of-life technology
- Lifecycle materials and resource efficiency, full chain of green manufacturing, maintenance and disposal

**3.4** Improve air operations and traffic management

- ATM supports mixed fleet (piloted and pilotless aircraft)
- Multi-criteria flight optimisation at aircraft level
- Full-time connected aircraft
- New ATM concepts
- Multiple trip aggregated optimisation with adaptive scheduling
- Full autonomy aircraft

**3.5** Improve the airport environment

- Emission free taxiing
- Prediction of aircraft NOx and particle emissions on airports
- Significant reduction of noise annoyance through technology benefits and improved noise management capabilities (modeling of noise effects, communication tools, land use planning best practices)
- Reduced & renewable energy use in airports (modeling of noise effects, communication tools, land use planning best practices)

**3.6** Provide the necessary quantity of affordable alternative energy sources

- Initial industrial application of advanced sustainable fuel production
- Low aromatic/sulphur fossil & renewable fuels
- Faster approval process for new drop-in fuels
- Evolution of fuel specification for optimised fuel-aircraft tandem
- Implementation of highly advanced low carbon fuel technologies (incl. non-bio-genic)

**3.7** Understand aviation's climate impact

- Good level of scientific understanding of contrail formation and impact
- Comprehensive climate impact models established

**3.8** Adapt to climate change

- Implementation of measures to adapt and build resilience to potential climate impacts for aviation
- Potential climate impacts for aviation researched and understood

**3.9** Develop incentives and regulations

- Policy instruments facilitating innovative investments
- First global harmonisation of sustainability standard

2020 2035 2050

# CHALLENGE 4
## Ensuring safety and security

Everyone wants air transport that is inexpensive, fast, punctual and environmentally friendly. But above all, it must be safe and secure. This balancing act is already a significant challenge. Although aviation is considered the safest mode of transport today, there are existing hazards such as severe weather and new security threats which need to be better understood and mitigated.

Added to this, aviation is an industry that does not stand still. It continually evolves, and will experience certain step changes between now and 2050. The future will see an industry that is ever more flexible and interconnected, with higher levels of automation, including autonomous and personal vehicles, as well as new, more ecological materials, cleaner propulsion fuels, and increasingly open and shared information sources. These will all bring significant change to current air operations. Change can be good, but it can also lead to safety and security vulnerabilities unless actively managed.

Dealing effectively with existing and future safety hazards, and growing security fears and threats, requires a fundamental shift in thinking about safety and security. Today these are largely dealt with separately, even though the travelling passenger does not necessarily discriminate between these two sources of risk. For this reason the main threads outlined below for research and innovation in safety and security follow a similar path. This will help create synergies between the two domains for the better protection of the travelling public and aviation businesses in the future. The five common action lines, and desired outcomes, are as follows:

**Governance**: strong safety and security management in organisations, and collaboration across the entire industry. This must be under-pinned via a pan-European regulatory system that supports stakeholders to actively engage in ensuring safety and security while staying in business.

**Human-system optimisation**: safe and secure performance and culture via all personnel at all levels, and in the case of security, dealing more closely with societal trends.

**Intelligence**: better sensors, and sharing and analysis of data. This will enable us to 'see around the corner' for safety, and provide a way to scan the security horizon.

**Safe and secure operations**: dealing with today's and tomorrow's threats and hazards via safety radar and continuous system behaviour and health monitoring. This includes adaptive security controls and inter-connected security operations centres.

**Resilient design, manufacturing and certification**: intrinsically safe and secure systems and products, with enhanced survivability, resilient to cyber and other attacks.

The following pages describe how, and by when, these action areas will be realised for safety and security, ensuring that businesses and services can grow while improving safety and security beyond today's levels.

| ACTION AREA | | 2050 TARGET STATE |
|---|---|---|
| **4.1** | Collaborate for safety | Europe operates an air transport system in which safety governance and practice is effective and able to stay ahead of the game in a rapidly changing environment. |
| **4.2** | Optimise human and organisational factors for safety | The system is designed to fully benefit from the human's ability to solve complex and unforeseen problems, thus ensuring the highest possible degree of safety. |
| **4.3** | Build and exploit safety intelligence | Vast amounts of data are available in the system. These are gathered, processed and exploited to provide vital information that makes the air transport system safer. |
| **4.4** | Ensure operational safety | Very high levels of operational safety are assured as a result of the measures described: strong collaboration, optimised human and organisational factors, effective use of data and a system designed for safety. |
| **4.5** | Design, manufacture and certify for safety | The system operates inherently safely due to the built-in resilience by design, manufacturing and certification. New systems do not hide any unsafe 'surprises'. |
| **4.6** | Collaborate for security | A framework is in place for system-wide security governance addressing policy, regulation and oversight. This addresses common risk management, minimum level of security and harmonised incident management. Security operations centres are in place across the aviation system. |
| **4.7** | Engage aviation personnel and society for security | Aviation personnel and society as a whole are fully engaged in security measures. Threats are identified and mitigated early and the public has enhanced confidence in air travel. |
| **4.8** | Build and exploit security intelligence | Data are effectively exploited for prediction of and preparation for emerging threats and vulnerabilities. Early warning facilitates prevention and response system-wide, thereby maintaining security across the entire aviation spectrum. |
| **4.9** | Ensure operational security | There is a sophisticated real-time security capability, supported by a global network of security centres. This builds public confidence and ensures overall system resilience and business continuity. |
| **4.10** | Design, manufacture and certify for security | Provisions for security are incorporated into design, manufacture, deployment and operations. The system is resilient to security threats with no inherent weaknesses. |

# ACTION AREA 4.1
## Collaborate for safety

The aviation industry has adopted **safety management systems** and high standards of certification which contribute to its excellent safety record. But aviation is a system of systems and is ever more fragmented, with new players arriving (e.g. RPAS manufacturers and users). It is therefore necessary to shift the concept of **safety governance** from one focused on individual organisations to one that harnesses the collective safety capability of all organisations across the entire air transport system.

A recent EASA-industry safety workshop concluded that the only way forward is through more collaborative approaches, initially by industry segment (airlines, air navigation service providers, airports, manufacturers) but ultimately in a broader system-connected way.

The landscape is complex and dynamic, with new types of operations, new aerial vehicles, new interactions and calls for inter-modality across diverse transport systems. All these will profoundly influence the aviation environment and, as a consequence, a 'compartmentalised' approach to safety will be inadequate.

Aviation is a global system and does not stop at national borders; neither should its governance. Safety governance needs the commitment of all European and even global aviation partners to ensure a coherent, **interoperable (joined-up) safety approach**. This means more collaboration within and across aviation industry segments, more sharing of best practices and data, more working together on safety issues, and **closer integration of safety management and business management**. It also means a better understanding of the short- and medium-term aviation safety impact of governmental and European-level policies, including in the wider **intermodal context**. This means interdependence with international stakeholders.

Overall, if a **collaborative safety governance** approach is achieved, it will mean that the entire industry can work more coherently, collectively and efficiently for safety, and can make better safety-informed decisions that affect both individual organisations and the industry as a whole in the shorter and longer term.

Getting the right stakeholders together and discussing safety is only half the solution. The other half requires having the right information to bring to such discussions. This means having **the right tools and methods** to accurately determine the risk impact of evolving hazards and threats.

It is necessary to develop the ability to **see around the corner** and not just wait for the next accident to show what should have been done. It must also be possible to pro-actively identify external hazards, such as those emanating from climate change. This will require new concepts, methodologies, performance measures and practical approaches. These will lead to an enhanced capability, a risk management system capable of reacting to known and emerging safety issues, whether at the level of an organisation, a segment, or the entire aviation system.

By 2030, safety governance must be pan-industry, pan-European and aligned within a global framework, each actor fully aware of its collaborative role in its operational and business context, and equipped with the right safety tools to inform collaborative decision-making. Intermodal safety governance is aimed at 2040.

### Expected impact

Europe will operate an air transport system in which safety governance and practice is effective, able to keep up with and stay ahead of a rapidly changing environment.

# ACTION AREA 4.2

## Optimise human and organisational factors for safety

In aviation today, humans are vital for the safety of the system, and it is fair to say that **'people make safety'** in aviation. Human Factors supports safety at the individual level, for example pilot and controller, considering aspects such as fatigue; at the crew level covering aspects such as shared situation awareness; and at the organisational level, safety culture.

But the context in which people and organisations operate is changing. There will be more automation and autonomy, more distributed ways of working in a multi-cultural environment, new business models, and a continued system performance requirement to monitor and support safe human performance in real-time.

The design of human-machine interfaces must be reconsidered to accommodate a new and wider range of aviation systems and user profiles. In particular this includes **increased automation**, as well as autonomous- and partially-autonomous personal vehicles for business, leisure and industrial uses. According to the degree of automation, the design must provide an effective and satisfying role for humans, preserving operator competence and ensuring service continuity in degraded modes. Information overflow must be avoided, and the risk of mode errors when shifting between different automation configurations or levels must be mitigated. The level of decision that is allocated to the system or to the human must be clear.

Research is therefore needed to develop **smart human-machine interfaces**, for highly automated systems. These should adapt to the specific user and operational context and thus support safe and efficient operations.

**New crew and team concepts** must be developed to embrace the whole air transport system. These must support collaboration across professional roles and between different organisations at national, regional and global levels, potentially extending to non-aviation specialists.

Planning must be done so that the **future workforce** is prepared for demographic and social change. Readiness must be assured to deal with new governance structures, new business models, challenges in achieving an industry-wide, pan-European just culture, increasing cultural variability (including the emergence of new players from outside Europe) and fragmentation of the aviation system. This is vital where safety is concerned since effective communication and cooperation amongst the different actors must be assured. This changing environment also demands that attention be paid to planning and preparation for **new skills and roles** with, for example, updated selection and training practices.

There will need to be a continued focus on key operational roles, such as pilots and controllers, to monitor and support the **human performance envelope**, detecting and compensating for problems such as fatigue, workload, vigilance, poor decision making, loss of situation awareness, and loss of control in real time.

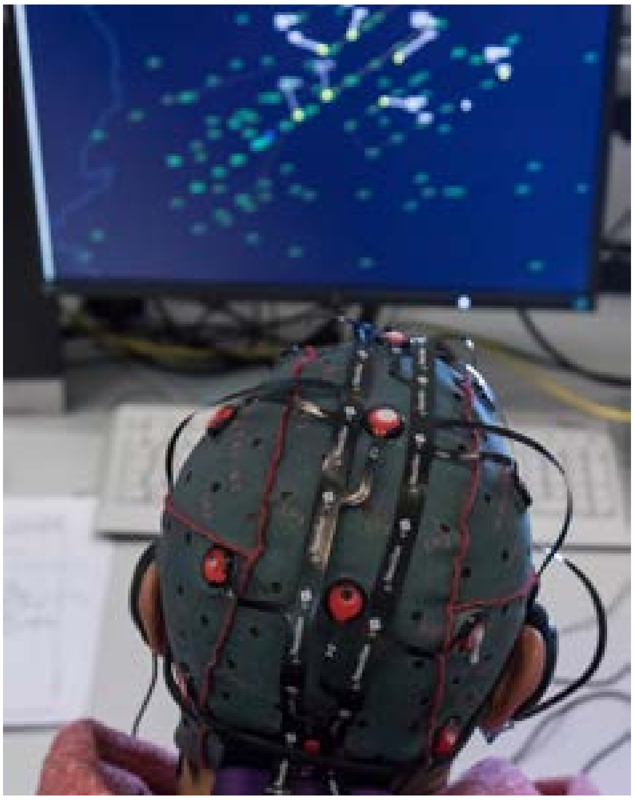
Smart HMIs and human performance envelope protection are targeted for 2030, with future workforce and new crew concepts aimed at the 2040 timeframe.

### Expected impact

The developments described here will ensure that the future system continues to benefit from the human's ability and ambition to solve complex and unforeseen problems, thus ensuring the highest degree of safety.

# ACTION AREA 4.3
## Build and exploit safety intelligence

For decades, a major approach in safety has been to learn from experience, that is, from incidents and accidents, but because the industry is very safe there are few learning opportunities. Furthermore, with an increased rate of change it is unwise to wait for things to go wrong – the industry needs to be more proactive, learn from successes and stay ahead of the curve. Until recently this has been difficult but now, with the advent of **powerful analytic tools**, it is time to develop a true look-ahead capability for safety.



This action area concerns the improvement and expansion of **data exploitation** for the benefit of safety in the European aviation system. The potential is broad, with applications ranging from commercial and general aviation, airspace and airport operations through to training and human performance. Included are enhanced acquisition of aviation data, its fusion, storage, processing, analysis, protection and visualisation.

Operational and safety-relevant data, correctly analysed, will yield information that will help improve our knowledge of the underlying dynamics of the system. **Machine learning** can be exploited to analyse data-rich descriptions of events and used to develop prediction paradigms to support safety decision-making. Furthermore, data models can help forecast the impact of changes in technology, regulation and operational procedures as well as human and organisational factors.

Management tools, methodologies and processes are needed for automated acquisition of data from multiple sources, including traditional recorded flight and operational data, as well as new sources such as weather, voice and video. Knowledge discovery and data mining algorithms, capable of detecting patterns across heterogeneous data sources can then be brought to bear. These can employ **big data** and **deep analytic techniques** to assess risks, detect causality relationships and identify new safety hazards. Visualisation techniques can be used to facilitate understanding and exploration of complex datasets.

The aviation system currently has many data sources, but they interact in a limited fashion, if at all. Restrictions often exist for reasons of privacy, legality or security, due to commercial concerns or technical incompatibilities. Strategies and policies must be developed to ensure that **confidentiality is not a barrier to exploitation of data for safety**, whilst still respecting data privacy.

Schemes must be developed to **manage safety intelligence**. These must ensure that the right information is distributed to the right stakeholders at the right time. Data must be presented in an easily accessible way using, for example, innovative visualisation techniques. Management schemes will cover all organisational aspects from top-level governance to real-time operations across the air transport system. A multidisciplinary approach will also focus on finding solutions to legal, privacy, commercial and security challenges.

Full safety intelligence capability, including tools and methods, sharing schemes and protection of privacy, is targeted for 2030.

### Expected impact

Vast amounts of data are already available in the system. Gathering, processing and exploiting them will provide vital information that will make the air transport system safer.

# ACTION AREA 4.4
## Ensure operational safety

Actions in this area are designed to ensure that air transport, the movement of air-vehicles, passengers, personnel and freight, operates safely. This must be done in the context of pressure to increase capacity and improve efficiency in an operational environment that is becoming more automated and more distributed.

Future developments in air transport vehicles and operations will be accompanied by new approaches to air traffic management. Airports and ground infrastructure will also evolve to better facilitate safe and secure transit for passengers and goods. The overall European air transport system must operate seamlessly with fully interoperable and networked systems.

There will also be an increase in the number and the diversity of vehicles with **different degrees of autonomy**, both in the air and on the ground, which will need to operate safely alongside manned systems. The complete landscape must be fully understood and supported by a comprehensive systemic **concept of operations**.

Special missions such as **search and rescue**, emergency medical services, firefighting, and aerial work, must remain safe and work unhindered in the majority of weather, atmospheric and operational environments. Innovative solutions are needed to **track and monitor flights** in all circumstances. It is also desirable to monitor the behaviour of key operational personnel and flag possible threats to the safety of operations.

The effects of all **weather** phenomena and other external hazards must be precisely evaluated and risks properly mitigated, in order to lead to weather-conflict-free routes. It is also necessary to extend research to consider environmental and weather hazards that may result from **climate change**.

To support these objectives a **safety radar** is required. This will use innovative methods, processes and services for near-real-time detection (e.g. with a look-ahead time of 15 minutes) of operational and behavioural deviations that could pose a threat. The safety radar must cover the total air transport system, and will depend on the availability of good safety intelligence as already described.

Research is also needed to **monitor system behaviour and health** with a view to self-healing for certain types of anomaly. This may apply to on-board and ground systems. **Maintenance** will also remain critical for mission safety, and new ways of enhancing maintenance performance and effectiveness must be developed.

Mitigation of existing weather, a concept of operations addressing all vehicles, and safety radar, are targeted for 2030. Mitigation of weather phenomena resulting from climate change is targeted for 2040.

### Expected impact

Ensuring high levels of operational safety is the culmination of all safety efforts. It is therefore indispensable for an aviation system that is globally safe.

# ACTION AREA 4.5
## Design, manufacture and certify for safety

Improved design, manufacturing and certification processes are needed to ensure safe and secure operations in a resilient air transport system. This starts with deeper understanding and modelling of phenomena leading both to safety risks, and safety successes. The issues to be considered are diverse, ranging from, for example, icing and lightning, to greater connectivity and high levels of automation. The final goal is to ensure an aviation system that is agile and **resilient by design**.

Studies should take into account the introduction of **new on-board safety technologies** with new human-system interfaces, protection against loss of control, improved sensors, turbulence detection and health monitoring.

Innovative approaches are needed to ensure that safety is an integral part of systems design starting at the very first phases, especially where disruptive concepts are being developed, and also encompassing other domains, such as occupational safety. **Modelling and simulations**, more accurate and detailed than before, must be available to support the entire development cycle.

Further study is needed on new system design techniques involving complex software and hardware, and **automatic code generation**, to understand their impact upon safety and security. Attention must be paid to the increased integration of functions and systems together with the human dimension across the entire life-cycle. **New simulation and virtualisation tools** will be needed to improve testing efficiency and coverage.

**Maintenance, continuous airworthiness and operational monitoring measures** must be in place to ensure the continuity of resilience throughout the system life-cycle.

**Certification** must also benefit from new simulation tools and capabilities to ensure the highest safety levels as well as **reduced time-to-market**, as developed in Challenge 2, even for the more complex and highly integrated systems. Simulation can be especially useful where experimentation is difficult, and for checking completeness of coverage. Certification rules must also make provision, at an early stage, for new and emerging technologies and concepts including, for example, RPAS (remotely-piloted aircraft systems). In such cases safety targets and certification requirements must take into account a dynamic landscape with short lifecycles for several classes of vehicle. This is a major change compared with traditional aeronautical systems.

A further concern to be addressed in both design and certification is the increasing use of **commercial-off-the-shelf software** and connected microelectronics. New techniques such as additive manufacturing and 3-D printing (see Challenge 2) must also be examined for potential safety issues.

Finally, studies are needed to improve **survivability** of people and goods in all types of aircraft.

New approaches to certification should be targeted at the 2030 timeframe, and full understanding and adoption of resilience-by-design in the 2040 timeframe.

## Expected impact

These actions will result in a system that is inherently safe, due to resilient design, manufacturing and certification processes. This means that new systems will not deliver any unsafe and unmanageable 'surprises'.

# ACTION AREA 4.6
## Collaborate for security

The future aviation system is expected to evolve significantly in the future, with the application of new operational concepts, the increased use of Commercial Off-The-Shelf (COTS) products developed using open standards, increased sharing of data and networking of systems, and the introduction of RPAS into controlled airspace. Developments in other industries have demonstrated that such a transition is not without risk, a dominant one at the moment being **cybersecurity**. The next generation of systems, as well as anticipated technological advances (e.g. the internet of things) may also introduce new vulnerabilities, the exploitation of which could result in undesirable impacts on aviation.

Security requires an **end-to-end approach**: there can be no weak links in the chain. This implies a holistic approach to risk management, addressing people, processes and technology. Security management must keep up with the persistent and dynamic nature of the threat. It must be intelligence-driven, asset-based and outcome-oriented.

This will require a suitable **security governance framework** which defines requirements for aviation security policy, regulation, and oversight at the state, regional and global level.

It is necessary for each aviation stakeholder to implement a common (or compatible) security management system, capable of operating seamlessly across the whole air transport chain. The scope must also include interfaces to critical supporting infrastructures, such as communication networks and satellite systems.

The approach to security management must not only consider all components of the system, but also the **whole life-cycle** of the system, from concept through design, development and operations, up to and including decommissioning. It needs to cover all aspects of **security risk assessment**, risk treatment, and incident and **crisis management**, including prevention, preparedness, emergency response, **operational continuity**, and recovery. The system must be capable of managing threats that have materialised, as well as those that have not.

A key driver of security management will be information received from security intelligence (see Action area 4.8) with a **security radar** providing information on current threats and vulnerabilities. Emerging future threats and vulnerabilities are identified via the process of **horizon scanning**.

It will be necessary to ensure that security across the system achieves a common, global, minimum level of performance. This should be supported by the governance framework, and will require the development of **security performance indicators** along with the means to evaluate, verify and validate security performance and to perform security certification of systems. State and regional security programmes must adopt a consistent approach at systems level. The security baseline will be fundamental in creating the necessary **trust framework**, motivating stakeholders to work together in a networked, data sharing environment. It will also support security monitoring, audit and liability considerations.

The governance framework must address the development of security operations centres, which will provide the platform for security incident management tasks to be carried out, including incident detection, identification, response, and recovery, using security intelligence and sharing information and alerts on incidents across the aviation system. These must involve organisations that understand local and regional issues and cultures, as well as international bodies to ensure global collaboration.

A longer-term objective is to **integrate the separate domains of security and safety** where this is feasible. These may be regarded as two sides of the same coin since they both seek to prevent harmful events, whether intentional (security) or unintentional (safety) in nature. An integrated safety and security management system may bring advantages such as providing an overview of risks and hazards, and may be able to exploit potential synergies in the implementation of controls while simultaneously dealing with incompatibilities.

These considerations extend beyond aviation into other modes of transport. Furthermore, transport is considered as critical infrastructure together with others such as the health, banking, energy, finance, water and digital infrastructure sectors. Aviation is already a system-of-systems, but is part of a much bigger family interconnecting with, interacting with and depending on many other systems-of-systems.

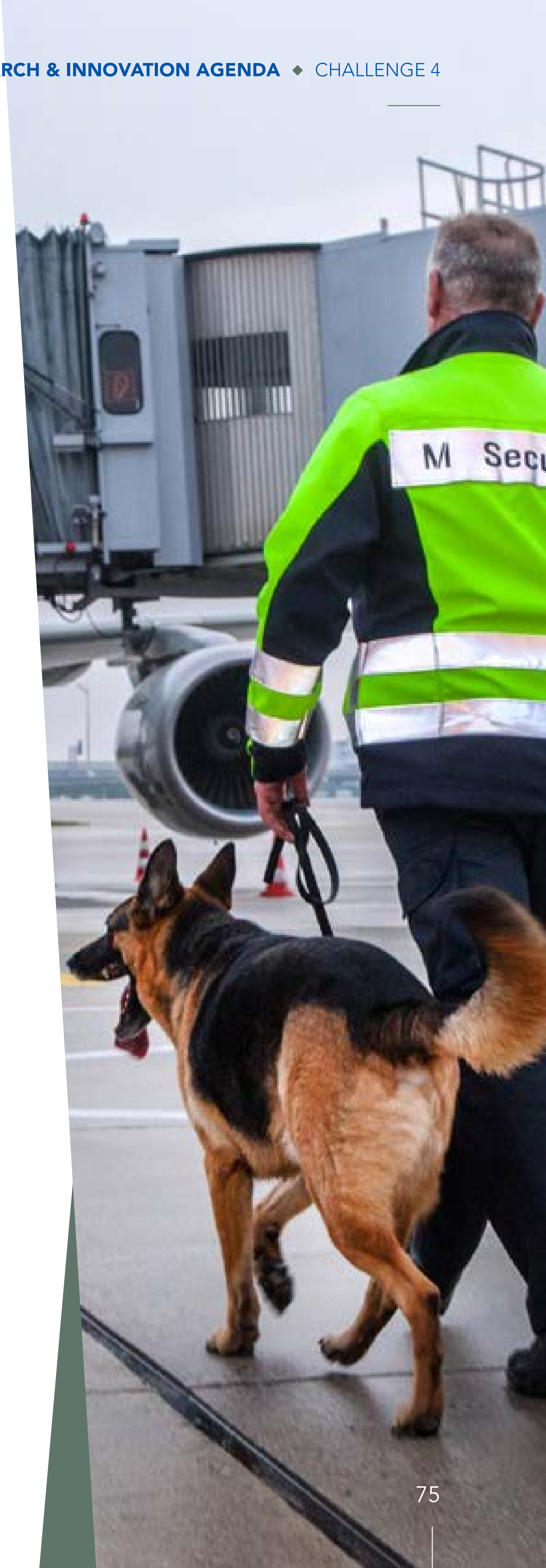
Failure to adequately address security poses a serious threat to aviation. There is an urgent need to perform the necessary research and develop the methods, tools, and procedures to support the end-to-end management of security. Studies on technical and organisational aspects should start immediately. Support for institutional and legislative frameworks should be discussed across the sector with a view to implementing full system-wide security schemes by 2025, extending to intermodal security governance by 2030. Security and safety collaboration is targeted for 2025.

The cost for a secure aviation system should be shared fairly between stakeholders.

The activities to ensure secure operations should have minimal impact on service delivery to customers, e.g. passengers, and need to be aligned with safety aspects of the operation.

### Expected impact

The actions described here are essential to mitigate security risks to the aviation system. They provide the framework to achieve appropriate system-wide governance to address policy, regulation and oversight, and the development and implementation of appropriate management systems. Together, these will address the means to achieve common (or compatible) risk management methods, a common minimum level of security, and a harmonised approach to security incident management with security operations centres across the aviation system.



# ACTION AREA 4.7

## Engage aviation personnel and society for security

People are central to security. Security is not only a matter of technology, but also of policy and procedure. It is effective only when proactive, informed human involvement is ensured over the whole life-cycle, creating a defensive layer that can protect individuals and society from harm. Security is a societal need and expectation to which authorities and regulators are obliged to respond. **The scope of actors able to introduce security threats into the system is greater than that considered in safety**.

Peoples' actions are shaped by their **national culture** and that of their organisation. Since aviation is a global business, perceptions of security and the way it is approached may differ substantially, so it is essential to understand the impact of these factors.

To address these issues, aviation must develop and nurture a **security culture**, in which people are motivated to follow established procedures, comply with regulations, and take the initiative when unforeseen circumstances arise.

This can be achieved via education, awareness, training and personal development, supported by an appropriate governance framework and security management systems (Action area 4.6). Innovative methods using, for example, computer-based training and gaming could be applied. The goal is to embed a risk-based security culture throughout the aviation system. Many lessons can be learned from safety.

Behaviours can be key to identifying threats and vulnerabilities, and this can be analysed through the use of innovative means to **monitor staff and passengers** using, for example, physiological measurement, the analysis of interactions at the human-system interface (e.g. personal devices), and the **analysis of social media**. The development of novel, non-intrusive means of monitoring will greatly improve their effectiveness. These areas should be exploited by developing and using new methods for the analysis of multiple data sources, such as those applied to the analysis of **big data**.

**Harmonised vetting procedures** for staff will be required to ensure a common level of security in the aviation system. It may be possible to predict the occurrence of threats and vulnerabilities through the analysis of **socio-cultural issues and trends**. All new information will be shared with the security radar and horizon scanning processes (Action area 4.8).

Research is needed to better understand and more optimally **manage cultural diversity** in aviation including passengers, crew, engineers, operators and security personnel. For emergency situations such as, for example, the management of disruptive passengers, this will improve outcomes.

A comprehensive programme of education in security culture should be developed now and be fully deployed by 2025. Ways of monitoring and analysing people and social trends for security threats should also be developed by 2025. Harmonisation needs to be achieved by 2030.

### Expected impact

The outcome of these developments will be enhanced awareness of security for aviation personnel and society, taking account of cultural differences. Threats will be identified and mitigated early, leading to a high level of security that provides the public with enhanced confidence in air travel.

# ACTION AREA 4.8
## Build and exploit security intelligence

Security must be supported by intelligence that provides the information necessary to develop a comprehensive and detailed catalogue of threats and system vulnerabilities. Tools are needed to automate detection of aviation incidents, gathering of associated information, and forensic analysis.

Current technologies and techniques should be adapted, and emerging approaches for data acquisition, storage, analysis and distribution should be exploited for this purpose including, for example, big data analytics.

A **security radar** must be developed to detect and identify security threats and associated vulnerabilities in real-time, allowing prevention and resolution actions to be taken. Information from the security radar is a key input to system-wide security management and operational security (see Action areas 4.6 and 4.9), driving the assessment and mitigation of risks in the aviation system.


A **horizon scanning** approach must also be developed to allow the detection of future, emerging threats to aviation from a variety of information sources, using the analysis of technology trends, socio-cultural trends and behavioural analysis. Information from horizon scanning will be provided to the security radar to allow it to address such threats and vulnerabilities as they emerge.

Specific methodologies, processes and simulation platforms must be developed to identify the best solutions and protection against the emerging threats in various scenarios, and to assess the resilience of the aviation system. These studies should suggest the **appropriate KPI for different types of scenarios**.

An important part of this area is **security information management and sharing**. The potential sources are many and varied and include airport devices, operational and passenger information, aircraft and air traffic management systems, system-wide information networks and open source intelligence. Information from computer emergency response teams, government, and security services must also be processed.

Real-time security incident information-sharing capabilities will enable **early-warning and alert mechanisms** to be engaged, facilitating incident prevention, preparedness and response actions.

Finally, information can be used to support post-incident analysis and develop lessons learned. Improved methods and procedures are needed for the **forensic analysis** of security incidents. This must encompass the efficient acquisition of key information on an incident, and its analysis in conjunction with other data sources such as the security radar and horizon scanning. Outcomes will support security-by-design (Action area 4.10).

Links must be initiated with all stakeholders who have a direct security interest so that work can start on building a comprehensive intelligence framework for mutual benefit across the industry. Standardisation and regulatory bodies should be involved as needed.

Security radar, horizon scanning and forensic analysis, along with information management and sharing, are all targeted for first implementation by 2025, with full system-wide capability by 2030. Intermodal provisions should be in place by 2040.

### Expected impact

These developments will provide the capability to predict and prepare for emerging threats and vulnerabilities. Early warning and alerts will facilitate incident prevention and response system-wide, thereby maintaining security across the entire aviation spectrum.

# ACTION AREA 4.9
## Ensure operational security

Since aviation is likely to be an ongoing target for a variety of threat agents, security must be addressed continuously during operations to ensure the safety of staff and passengers and continuity of service. This must be achieved while **maintaining system safety as well as performance**, with acceptable levels of capacity and delay.

Common (or compatible) incident management systems are needed to detect, identify, respond, and recover to normal operations in the event of an attack on the system. Information from the security radar (Action area 4.6) will be used to inform the **incident management** process of known threats and vulnerabilities. Sophisticated intervention methods, tools, technologies, and processes must be developed. These will be supported by intelligent decision-making capable of supporting human operators in high workload and high stress situations.

The capability to react semi-autonomously or autonomously to attacks should be researched, and approaches developed, for example, to anticipate **attack threat paths**, adaptively delay or neutralise ongoing or developing attacks, and **adaptively modify security controls** on anticipated threat paths.

Dedicated **security operations centres** must provide the platform for security incident management, including incident detection, identification, response, and recovery. They will use information received from various sources including **computer security incident response teams** and the security services. They will share information and alerts as appropriate.

Strategies must be developed that go beyond response and recovery considerations to include broader contingency planning for all affected people and parts of the system. This is part of the review cycle of the security management system.

Whereas the immediate objective in the aviation sector is to provide secure flight operations, this must be seen as part of the overall **door-to-door security** environment covering all transport modes. The integration of aviation security management systems with those of other transport modes and the sharing of information will provide clear additional benefit.

**Collaborative support** will provide services or information from aviation relating to an act of unlawful interference to law enforcement, military, search and rescue or incident investigation agencies. All operational facilities must comply with governance requirements and legal frameworks in place. It will be necessary for certain systems to be **security-certified**.

The security threat is immediate, so actions in this area must be initiated as soon as possible. Comprehensive coverage with interconnected security operations centres should be in place by 2030.

### Expected impact

These measures will deliver a sophisticated real-time security capability, supported by a global network of security centres, assuring public confidence and ensuring overall system resilience and business continuity.

# ACTION AREA 4.10
## Design, manufacture and certify for security

New trends in aviation include the increasing use of distributed systems, data sharing, automation, virtual operations, and remote monitoring and control. The presence of autonomous vehicles is expected to increase substantially. These present new security challenges which must be addressed immediately to ensure that the ultimate goal of a secure and resilient aviation system is achieved.

Security needs to be addressed from the beginning to the end of the **development life-cycle**, covering all phases from the initial concept, through design, deployment, operations and decommissioning. By applying a design-in approach, security requirements are obtained and integrated during development, avoiding costs and delays of bolting-on security later. This also avoids the situation where a fundamental re-design is required to address security risks identified late in the development process. Traceability through the whole life-cycle, and **secure change management** will also be of vital importance.

In order to achieve this, an appropriate security risk management approach must be in place (Action area 4.6), providing the necessary foundations for **design-in security**. This must include methods, tools, and guidelines for risk management activities during development, such as risk assessment and risk treatment. A specified **security baseline** (minimum level of security) is needed.

To support the achievement of a consistent, end-to-end, minimum level of security in the aviation system overall, the methods, tools and guidelines must comply with legal frameworks and agreed international standards, and be common (or compatible) across the aviation system.

Robust methods for developing **security-critical software** should be applied in the development of certain systems.

Systems developed to recognised standards will obtain a **security certification**.

Secure design, manufacturing and certification must be **a team activity** involving operational, technical, and regulatory experts working with safety and security experts. **Coordinating with safety** allows the exploitation of potential synergies in the implementation of controls, while simultaneously dealing with incompatibilities (Action area 4.6).

Systems must be secure against current threats, but must also be adaptable to the evolution of the threat landscape.

Consequently, information obtained from **security intelligence** must feed the design process.

Reciprocally, key design changes must feed the security intelligence to avoid the emergence of new vulnerabilities. In order to design **suitable secure systems**, specific studies involving stakeholders of the trust framework (Action area 4.6) should focus on **the consistency** between the definition of emerging security threats and the design cycle.

Security controls must be easily maintainable in order to minimise operational downtime. The system should be designed so that **system patches** are easily installed, and security controls can be incrementally enhanced with minimal effort.

When a security event occurs, the future aviation system must be capable of providing support to operators, who may be suffering from high workload and stress, to effectively address the threat. **Human factors** and psycho-social issues must therefore be addressed in the design process.

The system should be designed to alert operators to potential security events, and to **react semi-autonomously** or autonomously to attacks. The system should be capable of, for example, anticipating attack threat paths, adaptively delaying or neutralising ongoing or developing attacks, and adaptively modifying security controls on anticipated threat paths.

The **architecture** must support secure systems that comply with interface standards, interoperability requirements, incremental enhancement of security controls, and information exchange requirements.

A robust system acquisition strategy must be established which addresses the security risks as well as, for example, cost, schedule, capability and quality. This will ensure that potential **security risks associated with procurement**, for example in software development and manufacturing, are identified and mitigated.

New methods must also be developed for **testing**, along with innovative means to evaluate, verify and validate security performance during design, and in other development life-cycle phases. New approaches may include the use of **modelling and simulation tools** to demonstrate compliance to security requirements at component, product, system and system-of-systems level, addressing human, social and technical aspects.

In keeping with the international nature of the challenge, new systems must be studied, designed and manufactured to permit **global harmonisation** of security performance.

A design-in security approach is targeted for 2025, with full implementation aimed at 2030.

### Expected impact

Inclusion of security provisions in design, manufacture, deployment and operations is essential to ensure no inherent weaknesses in the system, and a system that is resilient to security threats.

# **Timeline for Challenge 4:** Ensuring safety and security

**2020 — 2035 — 2050**

**4.1** Collaborate for safety

- Performance based approach to safety
- Pan-European safety governancev
- Multi-modal safety governance
- Coordination of safety and security management
- Integrated safety and business management
- Long term impact on safety fro key decisions and societal change is modelled

**4.2** Optimise human and organisational factors for safety

- Optimised allocation of functions between human and automation
- New crew and team concepts for collaboration between roles and organisa-tions in a multi cultural setting
- Smart, adaptive human-machine interfaces adaptive to individual users and contexts
- Future workforce specification
- Human performance envelope protection

**4.3** Build and exploit safety intelligence

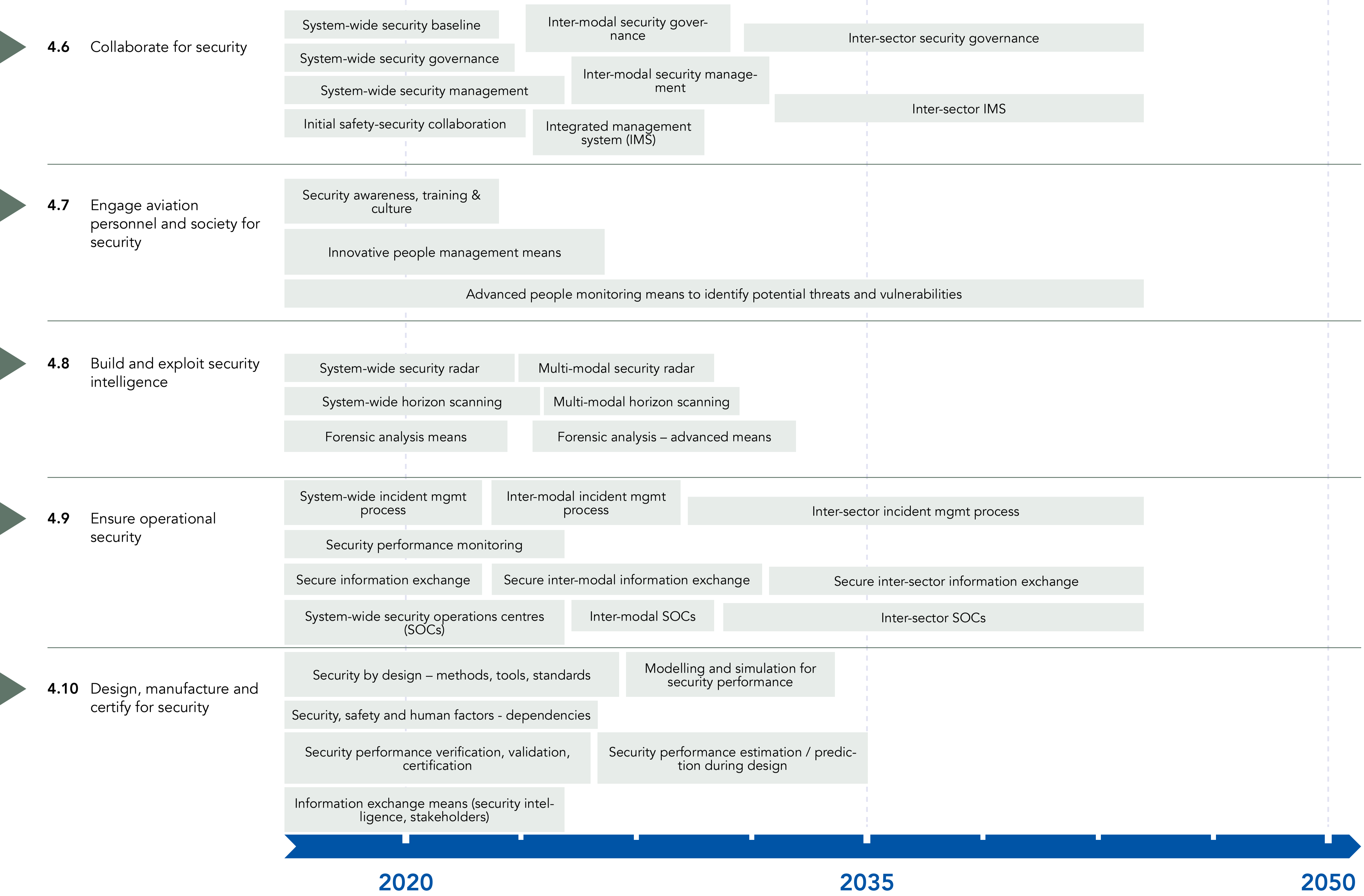
- Tooling and techniques for automated data capture, streaming fusion and storage
- Full sharing of information across stakeholders
- Technologies and processes for visualisation and distribution of data across ATS
- Mitigation of new weather challenges from climate change
- Pro-active safety analysis capability including weak signals, drift ino danger, and emergent threats

**4.4** Ensure operational safety

- Detection and communication of operational threats through improved sensor networks
- Health management and healing of materials and aircraft systems
- Improved post crash localisation and satelitte based tracking
- Functioning safety radar at both organisational and pan-European levels
- All weather capability of special missions

**4.5** Design, manufacture and certify for safety

- Improved simulation approaches reducing tmie-to-market
- New certification tools and processes leading to shorter time to market
- Improvements iin the design and manufacturing, leading to inherently safe operation and vehicles taking into account known and emergent hazards, and designing for enhanced survivability


4.6 Collaborate for security
System-wide security baseline
System-wide security governance
System-wide security management
Initial safety-security collaboration
Inter-modal security governance
Inter-modal security management
Integrated management system (IMS)
Inter-sector security governance
Inter-sector IMS
4.7 Engage aviation personnel and society for security
Security awareness, training & culture
Innovative people management means
Advanced people monitoring means to identify potential threats and vulnerabilities
4.8 Build and exploit security intelligence
System-wide security radar
System-wide horizon scanning
Forensic analysis means
Multi-modal security radar
Multi-modal horizon scanning
Forensic analysis – advanced means
4.9 Ensure operational security
System-wide incident mgmt process
Security performance monitoring
Secure information exchange
System-wide security operations centres (SOCs)
Inter-modal incident mgmt process
Secure inter-modal information exchange
Inter-modal SOCs
Inter-sector incident mgmt process
Secure inter-sector information exchange
Inter-sector SOCs
4.10 Design, manufacture and certify for security
Security by design – methods, tools, standards
Security, safety and human factors - dependencies
Security performance verification, validation, certification
Information exchange means (security intelligence, stakeholders)
Modelling and simulation for security performance
Security performance estimation / prediction during design
2020
2035
2050

# CHALLENGE 5
## Prioritising research, testing capability and education

Aviation is a high-technology sector which combines extraordinary demands on research and innovation with long lead times. Decisions on research and technology development may have consequences on the future of the sector, decades after they have been made. To maintain its world-leading position and competitiveness in the dynamic global market, Europe's aviation must be underpinned by world class capabilities and facilities in research, development, test and validation, and should provide to the current and future employees of the sector a top-level education that is adapted to its needs.

The majority of the actions described in this challenge are foundational for European aviation. This means that work needs to start immediately, defining schemes to make sure we do the right research, developing a coherent set of test capabilities and, maybe above all, providing world class education.

| ACTION AREA | 2050 TARGET STATE |
|---|---|
| **5.1** Maintain awareness with an effective technology watchtower | A strong technology watchtower is in place ensuring that the European aviation industry is globally competitive. In particular it will support OEMs with key knowledge and visibility of emerging technologies. |
| **5.2** Develop an inclusive research strategy covering the entire innovation chain | A coherent, integrated strategy ensures that promising research progresses easily up through the TRLs to implementation and operation. The strategy incorporates skills development that matches the technological demands. |
| **5.3** Make the right investment choices with robust selection processes | Agreed metrics support a robust selection process with clear prioritisation of research and technical development in support of ACARE goals. |
| **5.4** Develop and maintain state-of-the art test infrastructure | European investment in infrastructure is fully coordinated to support efficient, cost-effective testing. Facilities are state-of-the-art with substantial use of virtual test capabilities, ensuring high utilisation and providing significant benefits to the aviation sector. All stakeholders are engaged in a common approach and emerging trends are properly accommodated. |
| **5.5** Establish a sustainable network of operators for test infrastructure | There exists a dynamic and cooperative network of operators of strategic European test infrastructure, ensuring that up-to-date equipment is efficiently operated and maintained for the benefit of the aviation sector. Innovative business and operating models and funding schemes provide access to the testing capabilities for all stakeholders, including academia and SMEs. |
| **5.6** Provide world-leading education in aviation | European aviation education is world-leading, providing excellent support to the aviation sector. Programmes are harmonised with European accreditation schemes and a chartered aerospace engineer qualification. |
| **5.7** Stimulate the involvement of stakeholders in education | Industry and research establishments are fully involved in educational programmes ensuring that students are better prepared for a career in aviation. Industry is reaping substantial benefits from this collaboration, which extends to apprenticeships and life-long learning. |
| **5.8** Make aviation attractive to ensure inflow into educational programmes | The image of the aviation sector is positive and attractive. Sufficient numbers of people flow into the educational programmes and choose a career in aviation. This supports European aviation as world leader. |

# ACTION AREA 5.1
## Maintain awareness with an effective technology watchtower

Mechanisms are needed at European level to assess and evaluate research and technology developments that may be of benefit to the aviation sector. Scope must extend out to cover a wide range of applications, programmes and geographical regions, identifying new technologies, processes, regulatory and institutional approaches and so on.

As developments such as digitalisation, the internet-of-things and autonomy become pervasive, careful, systematic monitoring of other sectors has the potential to bring great benefit. A formal assessment network, a **technology watchtower**, will support this. It must be capable of keeping up with rapid developments in disruptive technologies.

The technology watchtower will promote harmonisation of evolutions in aviation with other relevant sectors, with **spin-in** and **cross-fertilisation** in a number of areas. It will help aerospace be more responsive to fast-evolving information technologies.

The purpose of the action area is to implement and develop the watchtower concept, to ensure it is focused and adapted to the task. It will monitor new developments while keeping traditional areas under constant review. A future vision must be created that includes breakthrough developments such as electric aircraft.

Lessons must be learned from other sectors such as marine, automotive, rail and energy. Particular attention must be paid to fast-moving areas of information technology, communications, big data analytics, internet-of-things and security. It must remain alert to the possibilities of **disruptive, step developments which may be currently unimagined**.

Furthermore, the watchtower must look at **innovative business models** that are able to better take advantage of new technologies. New processes are needed to help capture and import technology from other sectors.

An enhanced watchtower must be in place by the end of 2025. It will in the first instance generate a list of most promising and fast-evolving technologies and their roadmaps.

**Access** to the findings of the technology watchtower, which need to be regularly updated, must be made available **as widely as possible**.

### Expected impact

Aviation is traditionally seen as a leader in technology development, providing positive spin-off to other sectors. This leadership will continue as long as fast-moving developments from other sectors are effectively embraced and exploited.

A strong technology watchtower will ensure that the European aviation industry remains globally competitive. In particular it will be a support to SMEs with key knowledge and visibility of emerging technologies.

# ACTION AREA 5.2
## Develop an inclusive research strategy covering the entire innovation chain

The aviation sector must be organised to support the **full research and innovation chain**. In particular provisions are needed to ensure that research that has achieved an appropriate technical-readiness level can be further matured towards production and implementation. This will ensure a steady stream of new and improved components.

**OEMs and tier-one suppliers** need ambitious requirements to promote technology development and competition through the different tiers of the supply chain. This will enhance the overall competitiveness in the OEM's supply chain and enhance tier-one competitiveness worldwide.

There also need to be effective mechanisms in place to ensure that operational experience through the life of a product is **fed back into early-stage research**.

The sector uses the widely-accepted technology readiness level (TRL) method for classifying product maturity from basic research through to operational success. A complementary scale that measures skills capability is needed, so the adoption of an analogous **skills readiness level** (SRL) is proposed.

The main focus of this action area is then to ensure that the aviation sector has a fully inclusive TRL pipeline that starts with formation and education and progresses seamlessly through exploration, research, development, validation and demonstration to operations. Progress through technology readiness levels should be linked to advances in skills, introducing the notion of SRL.

Actions must also be taken to improve innovation and early-stage research through **lessons learned from demonstrations and operational experience**. This should be supported by better use of structured dissemination events: existing opportunities such as Aerodays and CEAS conferences must be better exploited, and these should be supplemented by new targeted events. Furthermore there needs to be greater collaboration between industry and academia with specific joint activities.

There must be better networking across the entire innovation eco-system, national, regional and global, with links at all levels. **Inclusivity** must be actively promoted. Improved selection processes (see Action area 5.3) will help identify areas that need specific skills, and will encourage synergies. More broadly, common skills, disciplines and topics must be shared wherever possible for the benefit of all.

**Policies** to support an inclusive research strategy over the entire innovation chain are needed in the short term. This embraces mechanisms to enable small and medium enterprises to link with higher-tier suppliers without penalty for sub-contracting.

The concept of skills readiness level to be used alongside technology readiness level needs to be developed by 2025.

Regular and targeted dissemination to support early-stage research should be initiated immediately with, for example, an annual Aerodays technology event.

### Expected impact

A coherent, integrated strategy will ensure that promising research can easily progress up through the TRLs to implementation and operation. Developing the right skills alongside the technology will ensure more robust product development. Systematic feedback from exploitation and operations into early research will ensure more effective technology development and reduce waste.

# ACTION AREA 5.3

## Make the right investment choices with robust selection processes

European research and innovation needs to be defined, organised and funded in a **coherent and coordinated** way, with minimum administrative burden. Publicly-funded programmes must be fully **transparent and accountable**. They must support business and promote efficiency while protecting intellectual capital.

Programmes must be linked to common objectives and roadmaps shared by stakeholders across the entire supply chain – this will promote suitable prioritisation of research.

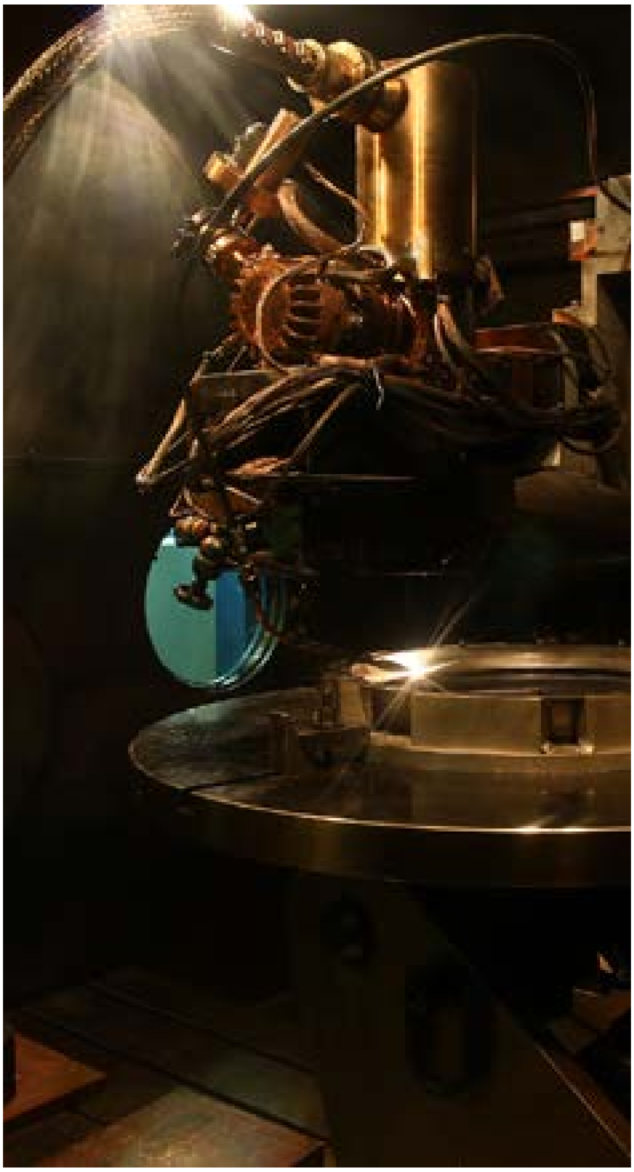
There needs to be greater use of common and agreed **metrics** to help guide investment choices, particularly in the case of low TRLs. These must allow for studies of alternative business models supported by new technologies. They must also support technology adoption where business risk is higher, encouraging entrepreneurial ideas from small, innovative companies. The metrics should be reviewed periodically to ensure they remain appropriate in the context of changing technologies.

The focus of this action area is then to develop metrics and goals to support the selection of projects and investments. Proposals for research and innovation actions (RIAs) should be judged with **reasonable flexibility**, but should be guided by the findings of the technology watchtower (see Action area 5.1). Innovation actions (IAs) should be selected taking into account agreed roadmaps, business models and objectives.

Selection metrics must be developed and maintained to keep pace with changing technologies, and must take into account different kinds of business model and timescale. Priority may be given to developments with the potential to rapidly enhance competitiveness through faster progress up the innovation chain. There must be positive stimulation for promising technologies.

Metrics must take into account **high-level societal and global goals**, while recognising that impacts are difficult to assess where technology readiness is currently at a low level.

A review of selection and prioritisation metrics and processes is needed by the end of 2017. This will help guide activities in support of overall ACARE goals taking into account the evolving technology landscape.



### Expected impact

The systematic use of agreed metrics as proposed here will provide a robust way of prioritising investment in research and technical development in support of ACARE goals.

# ACTION AREA 5.4
## Develop and maintain state-of-the art test infrastructure

A broad scope of test facilities is already available today for various tasks in the field of aviation research and development. They have traditionally been used for identifying and measuring physical parameters and for predicting the behaviour of the products concerned.

In recent years, **numerical simulation** has increasingly complemented or even replaced physical testing, with the aim of reducing costs and accelerating development. In particular, computer-based, multidisciplinary optimisation in the design phase of a product has the potential to **dramatically reduce the needs for physical testing** for verification and certification. Moreover, accuracy and fidelity are expected to further increase.

This trend will certainly intensify, shifting the principal role of physical testing more towards validation of simulation methods, tools and processes. As a consequence fewer, but more capable, test facilities will be required in many areas.

There is therefore a growing need for new infrastructure for numerical simulation and virtual testing. This will be supported by rapid developments in high-performance computing and data management, with big data analytics, data security and cloud-based architectures. An increasing share of investment in infrastructure will need to be dedicated to these new digital disciplines.

Both physical and virtual testing capabilities must be developed **to cover the entire innovation chain** from low-TRL research up to large-scale technology demonstration and certification.

Specific applications will include basic research, aircraft design and development, manufacture and assembly (Industry 4.0) and certification.

More broadly, facilities must also cover air traffic management and aircraft operations, maintenance, repair and overhaul as well as upcycling, recycling and disposal

The overall task of this action area is therefore to identify **requirements and targets for an infrastructure investment strategy** to meet the future needs of the European aviation industry. All stakeholders, in particular operators and potential users of infrastructures, must join forces.

First, an up-to-date inventory of existing infrastructure must be established. This will lead to the identification of needs which are not yet adequately covered.

In this context, **emerging industry trends and products** must be analysed. These may be highly diverse with developments such as unmanned aircraft, alternative fuels, electric propulsion, new production techniques and new air traffic management concepts. These are widely covered in other sections of this document.

New infrastructure should make use of technologies outside the scope of classical aviation disciplines. Areas of interest include computing, data management, electric systems, automation, digitalisation and Industry 4.0. Finally, it will be beneficial to develop **synergies with other transport modes** leading to, for example, shared use of infrastructure.

A basic inventory of current capabilities and requirements for new or updated infrastructure should be completed by the end of 2018. A systematic process for continuously monitoring future needs, and specifying and prioritising investment should be in place by 2025.

### Expected impact

Coordinated European investment in infrastructure will support efficient, cost-effective testing. Keeping facilities state-of-the-art will ensure high utilisation and provide significant benefits to the aviation sector. Engaging all stakeholders in a common approach will ensure that future trends are properly accommodated.

# ACTION AREA 5.5

## Establish a sustainable network of operators for test infrastructure

The aviation sector needs a coordinated and shared approach to the development, maintenance and operation of a broad range of infrastructure. This means that the various operators, public and private, must form a **sustainable network**, with a permanent process of collaboration. The network will bring together the expertise of all major operators, and serve as the counterpart to potential users in discussions on future needs and trends.

Transparent business models for governance, investment and operation are needed. These must employ best current practice and fully exploit potential European and national funding schemes.

The network will comprise primarily operators of those facilities that can offer a **high degree of accessibility to all stakeholders**. For infrastructure that is less accessible and more competitive, means of access should also be developed wherever possible.

The focus of this action area is therefore to first develop a collaborative network of infrastructure operators. This will involve large-scale facilities of strategic relevance to aviation research and development in Europe. The scope includes, inter-alia, an aviation computing network (or co-ordinating body); a network of aero and acoustic wind tunnels; a network of flying test beds and a network of ATM simulation platforms. The scope covers both physical and virtual capabilities.

The ultimate objective is to cover the **entire range of facilities** that needs to be available to a variety of users.

The collaborative processes in this network will address the development of business and legal models for infrastructure **provision and operation**. They will develop secure, barrier-free access for all stakeholders to the facilities. This may include a voucher system for academia and SMEs.

The network will identify emerging capabilities that need to be provided in the field of physical and virtual testing (see Action area 5.4). It will then coordinate European efforts in development and provision of new infrastructures. Finally it will define processes and mechanisms to make available sanctioned data as required, for example to establish an air traffic management system simulation capability.

A joint understanding among all European stakeholders of the strategic importance of existing test facilities should be reached as soon as possible. Then, before 2025, a network of operators of strategic facilities should be established, with basic processes defined.

In parallel, business models, funding schemes and mechanisms must be identified to provide **access to infrastructure for academia and SMEs**.

### Expected impact

A dynamic network of operators of strategic European test infrastructure will ensure up-to date, relevant equipment, efficiently operated and maintained for the benefit of the aviation sector. Utilisation will increase and redundancy will be reduced.

Innovative business and operating models and funding schemes will provide wide access to the testing capabilities.

Engagement of the network with stakeholders to define emerging needs and capabilities will ensure that the inventory remains up to date.

# ACTION AREA 5.6
## Provide world-leading education in aviation

The availability of a **workforce with excellent education** is crucial for maintaining leadership in European aviation. Professionals need the right knowledge and skills to address current and future challenges. World-leading education is essential at all levels, in all areas of aviation and for people at all stages of their career.

Europe is already a leader; it has a strong tradition in aviation education with many excellent schools and universities in several countries. In order to secure this position in the current changing world, it is necessary to go further, capitalising on the educational portfolio in Europe and preparing students for future needs.

In particular there must be a balance of **in-depth understanding and broad knowledge**, such as systems engineering and integration across disciplines. New, relevant developments in other fields such as big data and automated manufacturing must be incorporated. They must be included in educational programs while respecting total workload for the students.

21st-century skills such as **problem solving, critical thinking and creativity**, identified as priorities by the World Economic Forum, must be taught.

Forms of knowledge and skills transfer must be matched with overall objectives. This implies a mix of on-site and online programs, lectures, studio-classroom, laboratory work, project and teamwork, theory and practice.

Secure pedagogical methodologies and tools are required to modernise education with a life-long learning perspective.

To capitalise on the educational portfolio in Europe means fostering diversity, exchange and cooperation. To support this, the curriculum must be harmonised by means, for example, of the PERSEUS label for university education. Quality must be assured with a **Europe-wide standard for aviation education**, authenticated with a recognised quality label or by accreditation to a selected group of European establishments. This should be supported by a European chartered engineer qualification, managed and awarded by a respected organisation.

Deviations from the standard curriculum should, however, be accommodated with some establishments offering specialist skills for the benefit of the industry.

Finally, in addition to cooperation and exchange within Europe, links should be stimulated with **outstanding education institutes worldwide**.

Preparing our students for the future needs of aviation is a continuous endeavour and the actions described here must start as soon as possible. Between 2020 and 2035 educational establishments must increasingly give special attention to relevant technological developments in other fields.

By 2025 the means for harmonisation across European aviation education should be defined, with implementation following shortly thereafter. This will be followed by European accreditation which should be in place by 2035. The qualification of chartered aerospace engineer should also be available by 2035.

### Expected impact

As a result of these actions European aviation education will remain world-leading and provide excellent support to the aviation sector.

# ACTION AREA 5.7
## Stimulate the involvement of stakeholders in education

Education is essential to ensure a well-developed workforce in the European aviation sector. **Involving stakeholders** in this will be beneficial for the students, the educational programs, and especially the stakeholders themselves.

Stakeholder involvement will allow educational programs to receive up-to-date knowledge and training, and **inspire students** with real-world problems. It will give industry direct access to the talent pool, with the possibility to influence the development of their future employees.


Stakeholder involvement in aviation education can be stimulated in several ways and can take several forms, but the key is for people from both sides to **connect and work together**. This happens already to some extent, but it must be intensified and stimulated across all levels and countries.

The focus of this action area is therefore to ensure involvement of industry and research establishments in educational programs with advice on course content that addresses current and future needs. Internships, or topics for student projects, should be more widely available, as well as **placements and subject matter for masters and doctoral students**.

There should be more **staff exchanges**. Universities should invite more guest lectures from industry and research establishments. Longer-term exchanges should be possible with more guest positions for industry at educational institutions, and more possibilities for academic staff to take sabbaticals in industry. There should also be a greater number of **industry-funded university chairs**.

Mechanisms should be in place so that masters and doctoral students can participate in joint European projects, ranging from basic research to technology demonstrators.

These actions must start as soon as possible, at least before 2020, with the objective of having a significantly better quality of new recruits available to industry and research establishments in the 2025 timeframe.

### Expected impact

Involving industry and research establishments in educational programs will ensure that students are better prepared for a career in aviation. The benefits for the aviation industry will be substantial.

# ACTION AREA 5.8

## Make aviation attractive to ensure inflow into educational programs

A well-educated workforce is crucial for a world-leading aviation sector, and steps towards this are described in the previous two action areas. But there **must first be sufficient numbers of young people** interested in embarking on a degree and a career in aviation to ensure a good supply of qualified professionals into the industry.

To ensure a large enough inflow of talent into aviation educational programs we need to stimulate wide-ranging interest, starting with young people at primary and secondary schools in Europe. We should also aim to attract talent from outside Europe, those that wish to embark on a university degree and those that have already graduated and are fit for employment.

Measures are needed to ensure that **professionals at later stages in their career** remain fresh and motivated. Efforts should also be made to attract people from other sectors to pursue a career in aviation by providing good quality education adapted to their particular needs.

In order to ensure the availability of a large enough workforce we therefore need to **foster interest** in aviation in schools at all levels **from primary through secondary to higher education**. More widely, research and innovation in aviation should be promoted in an attractive way by outreach to the general public.

Degree programmes must be interesting, appealing, of high quality and supported by modern facilities. There must be plenty of capacity on courses to satisfy an increasing demand. There should be clear prospects on graduation of finding a good job, or of moving on to challenging postgraduate studies.

For aviation to reach a larger pool of talent, **gender balance** must be promoted to attract female students and encourage greater participation of women in conferences, events and competitions.

**International scholarships** may be used to attract top talent from Europe and outside to join aviation programs. Prestigious **prizes**, maybe modelled on XPRIZE, should be offered to boost motivation and innovation.

Careers must be visibly attractive and progressive, with **life-long learning** possibilities and the flexibility to change disciplines within the sector. Professional education and re-training opportunities should be available on-line or on-site

Awareness programmes for schools should be in place from 2020 onwards. Other kinds of outreach should also be in place from this date.

Europe-wide learning for the sector, partly online, should be available starting from 2020.

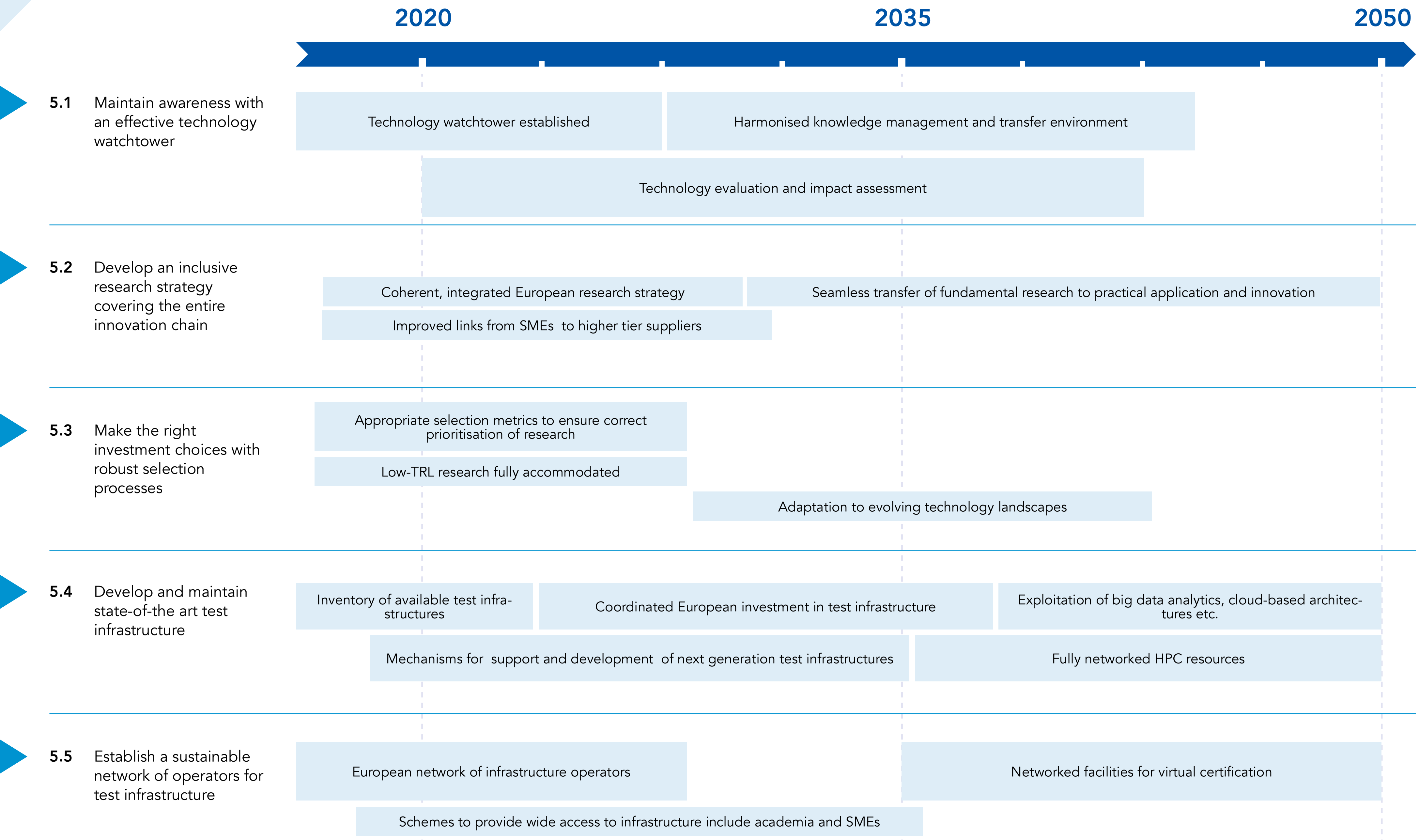
By 2025 there should be a system of grants for outstanding students who wish to join aviation programmes from within and beyond Europe. A European XPRIZE in aviation should also be organised by 2025.

Diversity in types of training, experience and culture should be explicitly and continuously prioritised with immediate effect.

### Expected impact

These activities will increase aviation's image as an attractive sector. As a result sufficient numbers of people will flow into the educational programs and choose a career in aviation. This is foundational for a world leading aviation sector

# Timeline for Challenge 5: Prioritising research, testing capability and education



**5.6** Provide world-leading education in aviation

- European education harmonised. with common , recognised qualifications
- European chartered aerospace engineer qualification
- Modernised syllabus, breadth and depth, 21st century skill-sets taught

**5.7** Stimulate the involvement of stakeholders in education

- Stronger connection between education, industry and research centres
- Industry participation in definition of educational content
- Staff exchange between industry and academia, guest lectureships etc.

**5.8** Make aviation attractive to ensure inflow into educational programs

- Aviation attractive at primary and secondary levels
- Full programme of education for professionals at later stages of their career
- Well-developed apprenticeships and graduate schemes
- International scholarships, prizes and other incentives
- Diverse and balanced workforce

2020 | 2035 | 2050

# ANNEX A: DEFINITION OF TERMS

| TERM | DEFINITION |
|---|---|
| 4-D | Four-dimensional |
| ACARE | Advisory Council for Aviation Research and Innovation in Europe |
| Aerodays | The EU flagship aviation event, held every few years |
| ANSP | Air navigation service provider |
| ASTM | An international standards organisation (originally American Society for Testing and Materials) |
| ATM | Air Traffic Management |
| CEAS | Council of European Airspace Societies |
| Clean Sky | A European JTI focused on innovative green technologies |
| Clean Sky 2 | The second phase of the Clean Sky JTI, started in 2016 |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide, a greenhouse gas |
| COP 21 | UN conference on climate change held in Paris, December 2015 |
| COTS | Commercial Off-The-Shelf |
| CSA | Coordination and Support Action – a funding device of the European Commission |
| Digital Economy | An economy based on digital computing technologies |
| EASA | European Aviation Safety Agency |
| EC | European Commission |
| ETP | European Technology Platform |
| Factories of the Future | A public-private partnership for competitive European manufacturing |
| Flightpath 2050 | Europe's vision for aviation, written in 2011 |
| GDP | Gross Domestic Product |
| GNSS | Global Navigation Satellite System |
| HMI | Human-Machine Interface |
| IA | Innovation Action – a funding device of the European Commission |
| ICAO | International Civil Aviation Organisation |
| Industry 4.0 | Next generation industry paradigm: cyber-physical systems, internet of things etc. etc. |
| ISO 14040 | Standard which describes the principles and framework for life cycle assessment |

| TERM | DEFINITION |
|---|---|
| IT | Information technology |
| JTI | Joint Technology Initiative – an EC mechanism for public-private partnership |
| JU | Joint Undertaking – an EC mechanism for public-private partnership |
| KPI | Key Performance Indicator |
| LCA | Life Cycle Assessment |
| MRO | Maintenance, Repair and Overhaul |
| NOx | Nitrogen oxides |
| OEM | Original Equipment Manufacturer |
| PERSEUS | An EU CSA for skills and education in European aviation |
| PPP | Public-Private Partnership |
| RIA | Research and Innovation Action – a funding device of the European Commission |
| REACH | An EU regulation concerning chemical substances and their risks |
| RPAS | Remotely-Piloted Aircraft System; UAV (unmanned aerial vehicle) and drones often used synonymously |
| SES | Single European Sky |
| SESAR | Single European Sky ATM Research |
| SESAR 2020 | The second phase of SESAR, started in 2016 |
| SJU | The JU charged with executing the SESAR programme |
| SME | Small and Medium Enterprise |
| SPIRES | Sustainable Process Industry through Resources and Energy – an EU PPP |
| SRIA | Strategic Research and Innovation Agenda |
| SRL | Skills Readiness Level |
| STRIA | Strategic Transport Research and Innovation Agenda |
| TRL | Technology Readiness Level. A "de-facto" standard metric that goes from TRL-1 to TRL-9. TRL6 is widely considered the end of the technology development cycle with TRL7-9 addressing the product development cycle. |
| UN | United Nations |
| XPRIZE | A globally-recognised prize competition for innovation on a range of subjects |

# BACKGROUND

The Advisory Council for Aviation Research and Innovation in Europe (ACARE) was formed following the launch of 'Vision 2020' for European aviation in 2001 by the European Commission with the help of a group of personalities. Since then significant progress has been made in European air transport and close collaboration by ACARE stakeholders has enabled the development of successive releases of the Strategic Research Agenda (in 2002, 2004 and 2008) which has served as guidelines for European research.

As a result of global changes in the first decade of this millennium, including better understanding in environmental science, advancing IT and economic downturn, more challenging goals were established by Flightpath 2050 in 2011. In response, ACARE developed a new Strategic Research and Innovation Agenda (SRIA) in 2012 to enable the new vision to be realised.

The first edition of the SRIA underlines the need for further emissions reductions, recommends maintaining and extending Europe's leadership, enhancing safety and security as air transport needs grow as well as developing excellent research infrastructure and education for the sector. However, even more significant changes have occurred in key parameters over the last five years. This has prompted ACARE to update the SRIA once more to reflect these dynamics in the latest priorities for research in aviation in Europe.

ACARE stakeholders continue to provide leadership for the whole air transport and aeronautics community and this collaborative framework is essential in developing an even more successful air transport system for the future in Europe.

More information: **www.acare4europe.org**