Realising Europe’s vision for aviation

Strategic Research & Innovation Agenda
Volume 1

Maintaining global leadership
Serving society’s needs

Advisory Council for Aviation Research and Innovation in Europe (ACARE)

September 2012
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Much has changed since the start of the millennium when a first Group of Personalities expressed a vision for European aviation ‘Vision 2020’, which led to the formation of the Advisory Council for Aeronautics Research in Europe (ACARE).

While the successive releases of the Strategic Research Agenda in 2002, 2004 and 2008 served as guidelines for European research established by the European Commission, member states and public and private stakeholders, a new vision was needed to be developed.

This prompted the sector to set new, more challenging goals and respond to the future needs of Europe and its citizens over a longer timeframe. This new vision, ‘Flightpath 2050’, was developed by the High Level Group on Aviation Research under the leadership of the European Commission and published in 2011.

It 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.

In response to the recommendations of Flightpath 2050 a new ACARE organisation (Advisory Council for Aviation Research and Innovation in Europe) with new membership is now in place. ACARE stakeholders have come together over the last year to develop the Strategic Research and Innovation Agenda (SRIA), presented here, that will enable the aims of the new vision to be achieved.

The strength of ACARE lies in its membership involving the whole air transport and aeronautics community. This collaborative framework is essential in developing an even more successful Air Transport System in Europe.

Further information about ACARE can be found on the following website:

www.acare4europe.org
Aviation is recognised as one of the top five advanced technology sectors in Europe. It provides close to nine million skilled jobs, directly and indirectly, and contributes 600 billion Euros to Europe’s Gross Domestic Product. Home to some 450 airlines and over 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.

Continued growth in European demand for air transport is anticipated for the foreseeable future. More than ever, sustainable mobility is at stake and it is essential that travel is safe, secure, fast, affordable and environmentally friendly. Also, industrial competition is fierce and increasing, not only from established regions but also from new, strong challengers. Finally, the regulatory and taxation environments within and outside Europe have not yet fully converged and prevent a global level playing field.

Maintaining global leadership for aviation in Europe and meeting the needs of citizens are thus the top level objectives that are addressed by ‘Flightpath 2050’. This vision for Europe’s aviation system and industry is now transposed into a Strategic Research and Innovation Agenda (SRIA) which provides details on the strategy the aviation sector commends to deliver that vision.

We invite all public and private stakeholders in European aviation to consider these priorities in their future research and innovation programmes and we look forward to making ‘Flightpath 2050’ a reality.
Thomas Enders,  
CEO of EADS  
Chair ACARE

“Aviation industry has achieved a lot in the last 50 years. Air traffic has grown by 50% in the last decade yet demand for aviation fuel has only risen by 3% - thanks to technology. Research and innovation are key to maintaining Europe’s capacities and competitiveness and it is time to align efforts towards the new long-term vision for this sector.”

Peter Hartman,  
President and CEO of KLM Royal Dutch Airlines  
Vice-Chair ACARE

“Aviation makes a substantial contribution to our economies, connecting markets and people worldwide. In the global picture European air transport can solely thrive by an avoidance of overregulation. Only in a global level playing field we can sustain our competitiveness, performance and sustainability. Setting up the priorities for policy, research and innovation will allow European aviation to remain safe, competitive, clean and secure.”

Marc Ventre,  
Deputy CEO and COO of Safran  
Vice-Chair ACARE

“The European manufacturing and service industry is facing new competition and new challenges. To maintain its leadership position, innovation is the key in all areas. Through innovation, we will preserve jobs in Europe, reduce the impact on the environment and increase our market share.”

Johann-Dietrich Wörner,  
Chairman of the executive board DLR  
Vice-Chair ACARE

“Aeronautics has an important role to play in reducing noise as well as greenhouse gas emissions to support sustainable traffic growth. Research, technology and innovation are essential catalysts for a competitive and sustainable future and we need to start quickly to be effective.”
In the last decade, Europe’s leadership in aviation has been underpinned by a commonly shared vision and an associated strategic research agenda. This proven methodology is deployed once more and extended to a new time horizon.

The new Flightpath 2050 vision addresses two parallel objectives: 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 including large companies and small and medium size enterprises. The vision identifies goals to reach these objectives and recommends addressing the following key challenges:

**Challenge 1:**
Meeting market and societal 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 capabilities and education.

According to this vision, in 2050, aviation serves society, brings people together and delivers goods through safe and secure,
Executive Summary

In its determination to meet the highly ambitious goals set by Flightpath 2050, the Advisory Council for Aviation Research and Innovation in Europe (ACARE) has developed a new Strategic Research and Innovation Agenda (SRIA).

Innovation in aviation is complex, capital intensive and takes time, partly driven by very stringent certification requirements, consistent with the paramount importance of safety in the sector. Typically, 15 years can elapse between the generation of a concept and technology being fully developed for a specific application on the next generation of air vehicles. In addition, a shift to a more customer centric and lower carbon operation has to be achieved requiring new airport operational concepts and development and the use of fuels fit for the future. Infrastructure development is dependent on the availability of excellent research, testing and validation capabilities. Vehicles additionally require platform integration and full-scale demonstration. For such reasons, the SRIA roadmap is phased over three timescales:

1. Short-term - to 2020
2. Medium-term - to 2035
3. Long-term - to 2050

The precise timing of implementing 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 European aviation world will also need to be underpinned by an efficient and effective policy and regulatory framework that addresses governance, funding and financing issues as a pre-requisite for the Vision 2050 to be realised. This framework should recognise the significant value of aviation to our economies and make sure European companies compete on a level playing field with their worldwide competitors.

The following sections provide an overview of the areas in which research will be conducted. The full SRIA document comprising Volume 1 and Volume 2 contains the comprehensive set of goals and actions that are required to address the five key challenges.
Sustainable mobility is essential for Europe’s economic development and social well-being. Synergies between good connectivity, wealth and prosperity, cohesion, international relations and stability are long-established and well-known.

Air transport must continue to support economic growth and add value at European, regional and local levels by providing the connectivity required by business, tourism and leisure, as well as providing local employment.

**Targets by 2050**

- European citizens are able to make informed mobility choices.
- 90% of travellers within Europe are able to complete their journey, door-to-door within 4 hours.
- A coherent ground infrastructure is developed.
- Flights land within 1 minute of the planned arrival time.
- 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 vehicles.

**Key action areas**

The following enablers are needed to achieve the goals:

1. **Design of a customer-centric intermodal transportation system:** including, for example, knowing future customer profiles and expectations as well as market and societal opportunities and acceptance factors, identifying the benefits and implementation issues of new mobility system concepts, design of the total transport system architecture, mobility performance assessment and forecast as well as innovative infrastructure planning methodologies.

2. **Travel process management:** to provide the customer a single ticket for the entire journey as well as travel information capable of delivering robust, relevant, complete and unbiased travel choice before and during a journey. This will also involve enhancing crisis management to mitigate the impacts of serious disruption by providing customers with a robust management and recovery mechanism as well as protecting their rights and interests.

3. **Integrated air transport:** offering customers a vastly improved seamless travel experience, integrating the points of arrival and departure of all types of air vehicles with other modes of transport, mitigating their impact on their neighbours, strategic and tactical air traffic management and supporting information, communication, navigation and surveillance infrastructure, and delivering system intelligence and autonomy.

**Challenge 1:**

**Meeting societal and market needs**
Challenge 2:
Maintaining and extending industrial leadership

The European industry is currently a world leader in aviation and contributes very positively to European economic welfare. Decision makers, stakeholders and society have recognized the strategic role of this industry and the need to maintain and extend its leadership through an appropriate and balanced regulatory framework putting European companies on a level playing field with their competitors from all over the world.

This leadership position will be maintained and extended by Europe’s industry remaining innovative and competitive, developing and delivering high quality products quickly and efficiently, meeting time-critical market demands and serving the customers’ needs for passenger, freight and non-transport services such as maintenance, repair and overhaul (MRO) and air traffic management (ATM). In 2050, innovative products and services demanded by the market are based on state of the art design, manufacturing and certification processes as well as support tools. They are underpinned by partnerships between manufacturers, airlines, MRO operators, airports, and air navigation service providers working together and collaborating with other modes of transport. Global regulation and standardization is strongly influenced by Europe, is light touch, streamlined and results in a global level playing field in the market for both products and services.

Research and innovation are supported by strong, coherent European research networks and partnerships between the relevant private and public actors, including industry, research institutes, universities and government.

Targets by 2050

• 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.

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

• Streamlined systems of 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.
Key action areas

The following enablers are needed to achieve the goals:


2. **Efficient development and manufacturing process** featuring seamless integration of design and manufacturing capabilities.

3. **Continued and focussed investment** in Research and Innovation to be at the forefront of new technologies.

4. A fair and balanced set of global **regulations and standards** to create a global level playing field.

5. **Innovative business models, regulations and incentives** to accelerate innovation.

6. **Efficient certification of aviation products.**
Challenge 3: Protecting the environment and the energy supply

Aviation has an important role to play in reducing greenhouse gas emissions as well as noise and local air quality issues. Although in global terms, the aviation industry is responsible for around 2% of human-induced carbon dioxide emissions, this may increase in proportion as other sectors move to “de-carbonise”, and as demand for air transport in Europe continues to grow.

The goals set by Flightpath 2050 in this area are profoundly ambitious and will only be met if better methods and processes facilitate the search for new solutions. More efficient aircraft and engines will need to be developed and integrated in radical new configurations to improve fuel efficiency and address climate change. Better operational and flight management procedures will also be needed to improve air traffic management efficiency. Improved maintenance technologies will also help to prevent degradation of fuel efficiency in ageing aircraft and thus reduce the flying fleet’s emissions. Improved understanding of non-C02 contributions to climate change - including NOx, particulates, and contrails and their dependence on operational parameters - will enable the sector to take a ‘cradle to grave’ approach to protecting the environment and the energy supply in aviation.

Targets by 2050

- CO2 emissions per passenger kilometre have been reduced by 75%, NOX emissions by 90% and perceived noise by 65%, all relative to the year 2000.
- Aircraft movements are emission-free when taxiing.
- Air vehicles are designed and manufactured to be recyclable.
- Europe is established as a centre of excellence on sustainable alternative fuels, including those for aviation, based on a strong European energy policy.
- Europe is at the forefront of atmospheric research and takes the lead in formulating a prioritised environmental action plan and establishes global environmental standards.
Key action areas

The following enablers are needed to achieve the goals:

1. **Dynamic allocation of targets between stakeholders, permanent survey of research results** and regularly updated research priorities.

2. Extraordinary technological effort to define the air vehicles of the future.

3. **Improved air operations and traffic management**, achieved initially through the deployment phase of SESAR, allowing for short/medium-term traffic growth in Europe.

4. **Improved airport environment** (including heliports) which, being at the heart of the intermodal transport system, must deliver a service that meets the needs of passengers while mitigating its environmental impact.

5. **Availability of affordable, sustainable, alternative energy sources** for commercial aviation which will depend on liquid hydrocarbons for at least several decades.

6. **Mastering aviation’s climate impact** to allow low impact operations planning, deeper analysis of the formation/dissipation of contrails and induced cirrus clouds and their contribution to global warming to evaluate the actual environmental impact of a given flight and to optimise flight operations according to atmospheric conditions.

7. **Incentives and regulations** that create the right framework to promote environmentally friendly behaviour as a part of business-as-usual throughout all lifecycle phases from new aircraft design and development, over the whole operational period, up to aircraft end-of-life.
Challenge 4: Ensuring safety and security

Aviation of the future, as a diversified and integrated transport system, will be tightly interwoven with other transport modes - surface and waterways. Methodologies need to identify the emergence of future risks such as cyber threats and data integrity and to accommodate these through improved design, manufacturing and certification processes.

New technologies will increasingly change the dynamic of design, operation, management and regulation of the air transport system. New standards and procedures will be required and a system-wide Safety and Security Management System will be implemented to operate throughout the whole chain of air transport activities.

The human dimension needs significant attention to ensure that in the future air vehicles, procedures and supporting systems are designed for the individual. The air transport system must demonstrate resilience in its response to safety or security threats, based on an understanding of human and organisational performance and how to infuse a positive safety culture at all levels and respond to a fast changing scenario.

Research must anticipate a more fully integrated interdependent system across all transport modes to identify, address and overcome the emergent characteristics of complex system operations.
Targets by 2050

• Overall, the European Air Transport System has **less than one accident per ten million commercial aircraft flights**.

• Weather and other environmental hazards are precisely evaluated and risks are properly mitigated.

• Air Transport operates seamlessly through interoperable and networked systems allowing manned and unmanned air vehicles to safely operate in the same airspace.

• Efficient boarding and security measures allow seamless security for global travel. Passengers and cargo pass through security controls without intrusion.

• 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.

• The Air Transport System has a **fully secured global high bandwidth data network**, hardened and resilient by design to cyber-attacks.

Key action areas

In addition, the following four key action areas will be targeted to achieve the goals:

1. **Expectations by society** for levels of safety and security, the associated burdens and the need to provide privacy and dignity.

2. **Air vehicle operations and traffic management** particularly relating to cyber threats and the integration of autonomous vehicles into airspace.

3. **Design, manufacturing and certification** to include safety and security at all stages.

4. **Human factors** accounting for re-alignment of responsibility and the balance of decision making between the human and the machine.
Challenge 5: Prioritising research, testing capabilities and education

Aviation is a high-technology sector which combines extraordinary demands on research and innovation with long lead times. Decisions in R&D may have consequences on the future of the aviation sector decades after they have been made.

To maintain its world-leading position and competitiveness in the dynamic global market, Europe’s aviation sector must be underpinned by world class capabilities and facilities in research, test and validation, and education as well as a world-beating workforce.

**Targets by 2050**

- **European research and innovation strategies are jointly defined by all stakeholders**, public and private, and implemented in a coordinated way with individual responsibility. This involves the complete innovation chain from blue sky research up to technology demonstration.

- **A network of multi-disciplinary technology clusters** has been created based on collaboration between industry, universities and research institutes.

- **Strategic European aerospace test, simulation and development facilities are identified, maintained and further developed.** The ground and airborne validation and certification processes are integrated where appropriate.

- **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.**

**Key action areas**

The following enablers are needed to achieve the goals:

1. **Optimisation of the research and innovation lifecycle:** encompassing the full European aviation sector, defining research roadmaps which cover all the successive steps of the innovation cycle.

2. **Modern infrastructure:** high quality R&D infrastructure as a fundamental pillar of efficient high-technology research, ranging from wind tunnels to experimental aircraft, all organized in a network for use by all stakeholders.

3. **A skilled workforce:** possessing the quality, skills and motivation to meet the challenges of the future; and being supported by a harmonised and balanced approach covering the entire scope: from attracting talent over primary and secondary education to apprenticeship, academia and life-long professional development.
To achieve the Flightpath 2050 goals for European Aviation, Europe must:

- **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 R&T 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.

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.

ACARE stakeholders are committed to continue playing a pivotal role in **providing the means for collaboration and cooperation** at a European and global level.

**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.
In 2050, Europe is the world leader in aviation. The customer centric, integrated European transport system is in place as described in the Flightpath 2050 vision. It is underpinned by standards, architecture, vehicles, intermodal business models and smooth processes enabled by the appropriate legal framework. These are the essential elements for seamless, door-to-door intermodal journeys. The costs and benefits of this transport system are distributed equitably along the value-chain. All of this is enabled by a new system engineering and development paradigm.

Customer needs are at the core of planning for infrastructure and services. These are optimised for their contribution to mobility goals and the delivery of intermodal, preference-based, door-to-door journeys under a single contract. Journeys are enhanced by innovative aviation services and customer processes. The performance of the entire transport system, including the aviation component, is immune to external factors, such as the weather, which, along with external atmospheric hazards, are precisely evaluated to allow the associated risks to be mitigated.

High-bandwidth communications are available to travellers for professional and personal connectivity, allowing a high level of resilience. This underpinned by optimised aviation services, which themselves are based on secured information, communications, navigation and surveillance technologies, systems and services. The European Air Transport System is unified through fully interoperable and networked systems allowing new manned and unmanned air vehicles to be integrated into and operate safely in the same airspace. Real-time flight optimisation combined with optimisation of the aircraft, the Air Traffic Management system and energy use has minimised environmental impact. Large scale sustainable, alternative fuel supplies are used in aviation.

Air vehicle fleets comprise a large variety of types with different capabilities. Commercial air vehicles are fully adapted to the air transport route structure, fully exploiting the efficiencies possible from advanced technologies and configurations to service the majority of air transport needs. Special duty and transport aircraft vehicles increasingly operate as Unmanned Aerial Vehicles. Special mission operations are able to operate safely and unhindered in the majority of weather, atmospheric and operational environments. General Aviation makes a significant and cost effective contribution to achieving the four hour door-to-door goal.

New vehicles fill gaps to create a fully intermodal transport system. These include, for example, innovative tilt and compound rotorcraft, conventional helicopters and ultra-quiet vertical, short take-off and landing vehicles.
All aircraft entering service are highly efficient and produce very low noise levels. They are economically feasible because of flexible, cost effective design, certification and manufacturing processes. They have radically new configurations that are adaptable to the mission cycle, exploiting morphing structures and systems enabled by intelligent controls. These new vehicles have fully integrated, embedded and/or distributed propulsion systems, utilising novel forms of energy, including electrical energy, as well as energy conversion, harvesting and storage. They are built with a new generation of materials and structures including nano- and biomimicry technology. They are designed for full recyclability and are self-repairable. With these highly innovative vehicles, the European manufacturing supply chain and maintenance industry has developed unique capabilities to deliver and maintain its innovative, high technology products both to Europe and on the global market.

Aviation continues to deliver the highest levels of safety and security to ensure that passengers and freight as well as the Air Transport System and its infrastructure are protected. General Aviation has become far safer due to the benefits derived from greater cockpit automation and designs, structures and propulsion. Air vehicles and infrastructure are resilient by design, offering improved survivability and emergency recovery capabilities. Intuitive and error tolerant human centred automation provides situation dependent functionality to maximise situational awareness, to support decision-making, and to enhance performance.

Security processes for air travellers are non-intrusive, preserve privacy and personal dignity. They are free of interruption and delay and allow seamless security for global travel, with minimum passenger and cargo impact. There is a balanced regulatory framework providing a maximum
of safety and security without burdening the aviation sector with undue costs.

International cooperation has never been more important. Europe has led the global harmonisation of standardisation and certification ensuring that aviation meets its demands and fulfils its obligations. The governance framework and associated rules for aviation are organised and applied on a global basis. Regulation and taxation systems are proportionate, harmonised and balanced on a level playing field for air transport operators and service providers both within Europe and across the world.

The Safety and Security Regulatory system has been globally harmonised ensuring high adaptability and responsiveness, anticipating emergent risks and facilitating the introduction of ground-breaking products and services. Simulation tools based on virtual reality are widely applied to demonstration of compliance with safety requirements at both component and product level.

A strong European Maintenance, Repair and Overhaul (MRO) sector services the world’s operators at competitive levels facilitated through appropriate social, fiscal and legal conditions.

While national establishments still run their specific research and training facilities, large and strategic infrastructures are operated on a pan-European level as an independent network of public research centres. Initially, this was based on the sharing of strategies between research establishments, initiated and supported by ACARE and now provides the facilities needed to achieve not only the Flightpath 2050 goals but also to tackle the whole mobility area with aviation at its nucleus.

Education and training for aviation needs are harmonised such that courses are fully interchangeable between countries. All students, in academic or vocational education, have the full choice of the place and time to study. Research projects and the use of infrastructure are integrated with European education. The best-of-the-best are recognised as such and set the standards to be followed. Courses are validated through a European accreditation system with processes and structures in place for setting and monitoring standards. New education tools have been adopted and are continuously developed by the major education organisations. The curriculum evolves to ensure scientists and engineers of the future can integrate interdisciplinary skills of a technological, human and social nature into a new systems science.

The Strategic Research and Innovation Agenda has proved the means to unify the views of aviation stakeholders and coordinate their plans. It has enabled Research and Technology Development policies and priorities to be aligned at industry, national and European level.
Introduction
Aviation\textsuperscript{1} is vital for our society and economy. It fulfils societal needs for suitable and sustainable mobility of passengers and goods over longer distances. It enables Europe to be connected to other continents and underpins Europe’s position as a geopolitical power. Aviation generates wealth, employment and economic growth for Europe. It contributes significantly to a positive balance of trade through export, provides high added value and highly skilled jobs and ensures European self-reliance. By fostering Europe’s knowledge economy it contributes significantly to the European 2020 Strategy.

The European aviation sector has many strengths but also scope for improvement. It operates in a highly competitive, global arena. Other regions of the world, both established and emerging economies, have recognised the strategic nature of aviation and are developing capabilities along the entire value-chain from vehicles, through infrastructure, to services, all supported by significant investment. The threats from this competition are very dynamic and real, both internally within Europe and to its exports on global markets. Furthermore, the regulatory environment within Europe has not yet fully converged. Major regulatory imbalances with other regions of the world can impede open and fair competition and distort markets. This affects airlines in particular.

Europe’s pre-eminence is therefore fragile – consider for example the negative impact of the disruption to the European air transport system because of the volcanic eruption in Iceland in 2010, which amounted to approximately €3.5 billion in the first week. To cement its leading position, Europe needs to keep ahead of

\begin{quote}
European aeronautics is a profitable and growing manufacturing sector. It numbers over 80,000 companies including a significant share of small and medium-sized enterprises. It provides highly skilled, sustainable, long-term employment - in 2009 it supported 468,300 highly skilled jobs and generated a turnover in excess of €100 billion. On average 12\% of aeronautical revenues are reinvested in Research and Development and support around 20\% of aerospace jobs. Europe also has a very significant air transport sector supporting 8.7 million jobs overall contributing nearly €600 billion to GDP through direct and indirect mechanisms. In 2010 in Europe there were 606 million air passengers carried on 7.9 million flights. Europe has 701 commercial airports and 448 airlines with approximately 6600 aircraft in service. European air traffic is managed by 45 air navigation service providers.
\end{quote}

\textsuperscript{1}For convenience in this document Aviation describes collectively aeronautics and air transport. Aviation comprises: air vehicle and system technology; design and manufacture; and also the constituent parts of the overall air travel system (aircraft, airlines, general aviation, airports, air traffic management, and maintenance, repair and overhaul) as well as many non-transport applications of aircraft, such as search and rescue.
developments elsewhere in the world. Furthermore, Europe must make the appropriate investment in aviation research and innovation to deliver advancing state-of-the-art, breakthrough products and services along the whole aviation value chain. These products and services must be brought to market – both within Europe and as exports – as quickly as possible. Research and innovation must be supported by research and development infrastructure, by knowledge and by technology transfer from and to other related sectors. One of the key building blocks is an education system, closely tuned to and in partnership with industry that delivers a highly skilled and flexible workforce. An optimised policy framework is also vital to success.

Over the last decades, aviation in Europe has established a tradition of cooperation and collaboration. The report of the Group of Personalities (GoP) – «European Aeronautics: A vision for 2020», published in 2001 set the two top level objectives for Europe: Meeting society’s needs and winning global leadership. For the realisation of these objectives, the GoP prompted the creation of an Advisory Council for Aeronautics Research in Europe (ACARE), comprising stakeholders drawn from public and private organisations in the European aeronautics and air transport sectors. ACARE was established to bring together authoritative, senior figures from aeronautics stakeholders, Member States and the European Commission and build consensus in favour of strategic actions to facilitate the development of the European Aeronautics Sector.

Priorities for research policy and funding were addressed through the publication of a Strategic Research Agenda (SRA). These forward thinking documents provided significant influence on the direction of aeronautical research in Europe and beyond thanks to widely accepted reference targets and goals. The implementation of the SRA via European and national, public and private programmes was a key element in achieving and maintaining Europe’s leading position in the aeronautical sector, while at the same time supporting society’s needs.
The Strategic Research and Innovation Agenda for Aviation

In 2011 the High Level Group on Aviation Research published “Flightpath 2050 - Europe’s Vision for Aviation”. This document recognised the challenges that had evolved since the initial launch of ACARE and addressed two parallel objectives: maintaining global leadership and serving society’s needs. It has identified goals to reach these objectives and address the following main challenges:

**Challenge 1:**
Meeting market and societal 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 capabilities and education.

Flightpath 2050 recommended the development of a new Strategic Research and Innovation Agenda (SRIA) for Europe by a rejuvenated ACARE. Based on this, the scope of ACARE was broadened to encourage a more active participation by organisations engaged in air transport operations, to complement the existing strong engagement by the aeronautical industry; to address the full scope of aviation topics in the context of the whole European transport system; and, to consider the full range of issues necessary for innovation, including but not limited to, research (e.g. including policy, business, societal and technological change). As a consequence, ACARE was renamed the Advisory Council for Aviation Research and Innovation in Europe with the mandate, amongst others, to prepare and implement a new SRIA for Europe.

Today **Europe is a world leader in aviation**: The SRIA is a vital contribution to maintaining and extending this leading position and to increasing Europe’s competitiveness in the future, while continuing serving the needs of the society, in Europe as well as all over the world.

The **aim** of the SRIA is to provide a research and innovation roadmap to reach the goals highlighted for each Challenge in Flightpath 2050. The roadmap highlights the priorities for aeronautical and air transport research and innovation, and the related public policy issues to be addressed to support these priorities. The roadmap addresses three timescales: **short-term** - to 2020; **medium-term** - to 2035; and **long-term** - to 2050.

The **scope** of the SRIA comprises all the aspects of aviation necessary to achieve the goals of Flightpath 2050. It addresses:

- The science, engineering, manufacturing and in service support of civil air vehicles and aviation products.
• The development and operational management of the air transport system, as part of an overall transport system.

• The impact of aviation on the environment, including the emissions, and noise generated by air vehicle operations as
well as the impact of the product lifecycle, including manufacturing, operation, maintenance, recycling and disposal.

The SRIA has been developed following a structured process as illustrated below.

The goals associated with each of the challenges identified in Flightpath 2050 were first analysed. The key enablers and capabilities needed to tackle these challenges were then identified and described. Then the metrics used to define and monitor progress were specified and the research needed to develop the capabilities was defined.

The SRIA is presented in three documents, encompassing research and innovation issues of relevance for the European Union, national governments, regulatory authorities, industry, research centres, and academia. It is a joint initiative by all stakeholders involved in aviation research and innovation to provide guidance for future decision making on matters of policy and strategy.

The Executive Summary has been prepared for high-level decision makers and is also available as a stand-alone document.

This document is Volume One of the SRIA and describes the full scope of issues relevant to future research and innovation in aviation. It answers the what and the how questions.

Volume Two has been prepared for a target readership of research and innovation actors. The fullest detail of the agenda is presented, which defines the goals from Flightpath 2050, into a series of specific and time bound research and innovation objectives to guide the work of research and innovation teams across Europe. Volume Two thus addresses the when and with what questions as well as providing information on policies and legislation. Volume Two is accessible on the ACARE website www.acare4europe.org
Challenge 1

Meeting societal and market needs
1.1 Introduction

Sustainable mobility and the supporting air transport business activities are essential for Europe’s social well-being and economic development. The inter-dependencies between good connectivity, wealth and prosperity, cohesion, international relations and stability are long-established and well documented. Air transport must support economic growth and add value at European, regional and local levels by providing the connectivity required by business to support export and inward investment as well as providing local employment both directly and indirectly.

Mobility is also very important for social reasons, for example to enable visits to friends and relatives and for leisure and tourism.

Meeting societal and market needs is about enabling mobility for both passengers and freight. The seamless door-to-door travel chain is a principal societal requirement. This needs the design and implementation of a resilient, sustainable and customer-centric intermodal transport system that meets European mobility goals.
The total transport system of the future is integrated, energy-efficient, diffused and intermodal. It takes travellers, their baggage and freight from door to door, safely, affordably, quickly, smoothly, seamlessly, predictably and without interruption. Aviation takes the leading role in realising the system and associated services in close cooperation with other transport modes and is at the core of its operation.

The future Air Transport System meets evolving demands to realise benefits for all stakeholders. These demands are defined quantitatively for all categories of customer, be they passengers, cargo or other users of the system. Customer demands are also defined in terms of many quality factors such as price and ease of journey, journey time, environmental impact, frequency and service quality (whether the flight is direct or connecting, seating comfort, cabin ambience and so on).

Customer and societal acceptance of new processes and techniques is critical and is assured, particularly when new concepts require the sharing of personal data and the delegation of responsibility and authority from the human to the machine (automation). Society recognises that air journeys are safe and secure. Data privacy and security are guaranteed. Safeguards ensure that personal data and journey information provided by customers are used responsibly and contained within the transport community. These data are only used to support the successful delivery of the journey and not for other purposes whether malicious or otherwise.

Passenger and cargo processes at airports are streamlined and rapid. All checks for security and immigration are conducted smoothly and in a non-intrusive manner. It is possible for these checks to be made during other legs of the door-to-door journey and/or during journey planning.

Air transport continues to support the political objectives of European cohesion and furthering European integration. Delivering the benefits of integration and a sustained commitment to minimising aviation’s adverse impacts remain critical to achieving social acceptance. Expansion of the air transport network is planned and executed in partnership with the regions involved to deliver the maximum regional added-value.

High speed data and power connections are provided to passengers, irrespective of class-of-travel, enabling continuous access to global high-speed personal communication, internet services and applications for work or leisure throughout the entire journey. These services are also used to facilitate speed and convenience by providing dynamic information to the customer at all stages of the journey. Executive passengers have access to a truly flexible and rapid air transport service providing uninterrupted flying office facilities.

The customer experience is paramount. Transformation from engineering-centric facilities to customer-centric services is complete. A number of choices are available to the many different types of passengers. Customised products and services offer levels of facilities, quality of service, on-board comfort, journey time, optional rescheduling and price tailored to different types of passenger.
Customers are served by a fully integrated travel management solution, enabling them to establish a **single-point transport contract for door-to-door services** rather than having to deal with diverse service providers for different modes of transport. Through ticketing is based on a single ticket and single contract. Baggage can travel from door-to-door independently of the passenger.

**Automatic journey management systems** provide passengers with real-time information and automatic rescheduling, including change of mode, in the case of disruption. Most proposed journeys are planned and purchased on a door-to-door basis including intermodal segments and customer preferences.

**Freight forwarders and shippers have similar choices to passengers** regarding price, service level, and journey time. Cargo remains an important component of the payload on passenger aircraft, and unmanned aircraft vehicles (UAVs) are playing an increasing role as freighters.

**Non-transport aviation missions** have increased significantly. These missions are undertaken by a mix of fixed-wing, rotorcraft and unmanned aircraft. UAVs are used especially for predictable and repetitive, dangerous and long endurance tasks. These include new applications, for example providing part of society’s information infrastructure, emergency services, disaster relief. Rotorcraft continue to play a significant role in a very wide range of public services and have expanded their spectrum with the emergence of new vertical take-off and landing (VTOL) solutions enabling formerly impossible missions due to their high speed and long range capabilities.

A range of **new air vehicles and air vehicle operating concepts** exists, offering the passenger a range of choices to best meet individual requirements and preferences.

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**FLIGHTPATH 2050 GOALS FOR CHALLENGE 1**

1. **European citizens are able to make informed mobility choices** and have affordable access to one another, taking into account: economy, speed, and level of service (which can be tailored to the individual customer). Continuous, secure and robust high-bandwidth communications are provided for added-value customer applications.

2. **90% of travellers within Europe are able to complete their journey, door-to-door within 4 hours.** Passengers and freight are able to transfer seamlessly between transport modes to reach the final destination smoothly, predictably and on-time.

3. **A coherent ground infrastructure is developed** including: airports, vertiports and heliports with the relevant servicing and connecting facilities, also to other modes.

4. **Flights arrive within 1 minute of the planned arrival time** regardless of weather conditions. The transport system is resilient against disruptive events and is capable of automatically and dynamically reconfiguring the journey within the network to meet the needs of the traveller if disruption occurs. Special mission flights can be completed in the majority of weather, atmospheric conditions and operational environments.

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,** including unmanned and autonomous systems that are integrated into and interoperable with the overall Air Transport System with 24-hour efficient operation of airports. European air space is used flexibly to facilitate reduced environmental impact from aircraft operations.
1.3 The enablers to reach the goals of Flightpath 2050 for Challenge 1

Enablers describe what is needed to achieve the goals. Capabilities describe how the goal can be achieved. The general enablers needed to realise the goals associated with Challenge 1 are as follows.

- **Creating the basics:** develops the underlying research and knowledge required to initiate and support work in the following two clusters. These capabilities are the foundation of an intermodal transport system. This encompasses the customer expectation and role as an active participant in the travel chain as well as understanding market and societal opportunity and acceptance. It also covers identification of the benefits of the new mobility system concepts, issues relating to their implementation, the design of the intermodal transport system and mobility performance assessment (including infrastructure development based on its contribution to mobility goals).

- **Travel process management:** is about providing a customer travel management tool capable of delivering robust, relevant and complete travel choice information to customers before and during a journey. This ensures that travel choices are presented to customers in a fair and transparent manner, building bridges with information technology (IT) developments in other sectors to enable intelligent travel by rapid development of value-add applications relevant for transport mobility. It also enables the impacts of disruption to be mitigated by providing customers with a robust management and recovery mechanism as well as protecting their rights and interests and enhancing crisis management.

- **Aviation:** covers the nodes used by all types of air vehicles and their connection to other modes of transport. It encompasses strategic and tactical air traffic management along with the supporting information, communication, navigation and surveillance infrastructure. It also includes system intelligence and autonomy. Environmental mitigation (noise, air quality, etc.) is addressed in Challenge 3.
1.4 Creating the basics

1.4.1 UNDERSTANDING THE CUSTOMER EXPECTATION AND ROLE

The seamless, intermodal transport system is customer-centric. It is based on the two main pillars of mobility delivery: the expectations (demands) of the customer, including safety and security; and the dependency of the travel and transport system on the customer.

Knowledge of the customer profile is essential to tailor the system to meet expectations. This profile covers characteristics such as demographics (e.g. age and size profile, cultural background, economic well-being); passenger types and their way of travelling (individual, group, escorted, etc.); as well as attitude to regulation, and privacy issues associated with the sharing of personal information.

Customer expectations and requirements are the basis for the design and delivery of the best possible end-to-end travel experience to each individual traveller. These requirements cover a range of factors, such as the trade-off between travel time, quality, environmental impact, punctuality and price. They take into account all aspects of the travel process (such as airport access, security, baggage processing, terminal ambience; immigration checks); as well as door-to-door integrated and customised services. Customer expectations are the basis of a roadmap that guides the evolution of airline and airport business models.

Crucially, the design of the customer-centric Air Transport System (ATS) includes the definition of customer roles in the cooperative transport process. Following the customer-centric principle, customers’ expectations and requirements are integrated into the door-to-door journey roadmap. The evolution of this roadmap is regularly monitored, adapted and controlled.

Finally, and critical to success, the system is built on a firm understanding of customer expectations concerning safety and acceptance of potential additional cost or inconvenience to increase safety levels even further.

1.4.2 MARKET AND SOCIETAL OPPORTUNITY AND ACCEPTANCE

The ATS is built on acceptance or, at least, tolerance by both society and the market. Showstoppers have been overcome, including, for example the use of personal information, location data, etc. On-going development is based on the opportunity to exploit new initiatives (beyond the basic expectations) both for the market and society at large.

Socio-political acceptance is built on an understanding of the regulatory and legal implications of evolutionary and step-changes in the responsibilities, rights and obligations of stakeholders. These stakeholders include operators (pilots, air traffic controllers, etc.) and providers and customers of transport and travel services. Europe-wide minimum service and quality standards are defined along the entire aviation value-chain.
The legal implications of **integration of unmanned and other innovative aerial vehicles into civil airspace** are understood. The appropriate definitions and regulations are in-force, securing appropriate levels of safety.

Global and regional **socio-economic factors** are monitored and their implications for the transport industry understood. These factors may include trade patterns, economic and market development, cultural diversification, globalisation, energy prices and operators’ business models. **Transport policy** is optimised with air transport and intermodality at its core. Policy is based on knowledge of the implications of subsidy and the impact of intermodality on stakeholders.

To ensure customer acceptance, adequate personal **data protection** is built into the overall system to ensure the protection of privacy, personal dignity and data. **Market acceptance** is facilitated through an understanding of uncertainty factors and capturing those factors which may influence and impact development of the aviation industry. This understanding is kept up-to-date by monitoring the **global and regional evolution of the air transport**. Shifts in market balance to other regions are anticipated and fair access by European actors to those markets is assured. Furthermore, market acceptance is enabled by identification and development of clear **business cases** highlighting the attributes and specifications necessary for a seamless traveller experience across different modes.

To ensure **community acceptance**, the importance, nuisance and cost of security in the total transport system is understood (see also Challenge 4). Coherent security strategies are applied to all modes and facilitate seamless intermodal security. The public appreciates fully the security mission and associated measures.
Societal acceptance of the impact of transport infrastructure and operations in the neighbourhood of air transport nodes is assured. This is built on robust understanding of the influencing factors along with appropriate communications strategies and mechanisms developed in the light of technological and operational developments (see also Challenge 3). Optimised transport asset management, including both land and airspace management, creates broad social acceptance of the needs for transport, balanced with neighbourhood interests, and fosters political awareness.

The safety challenges posed by automation, including autonomous operation and management of air vehicles and pilotless aircraft, are addressed from the perspectives of both passengers and citizens being overflown (see Challenge 4). This creates societal acceptance of the increasing level of automation in the (air) transport system.

1.4.3 ASSESSMENT OF NEW MOBILITY SYSTEM CONCEPTS

Policy and strategy development are informed by methodologies and frameworks to assess the impacts of technologies, processes and integration.

Specific research programmes are established to facilitate the development and deployment of new mobility concepts in an intermodal transport environment. Implementation challenges are identified and addressed at an early stage. This provides sufficient evidence to validate that potential contributions, from new vehicles, technologies, concepts, etc., meet or exceed customer mobility expectations. It also facilitates their implementation.

New mobility concepts are evaluated using open architecture transport system modelling. A modelling toolkit is established that includes tools for strategic, tactical and real-time transport modelling and simulation. It has the capability to assess, optimise and trade-off different options considering the whole range of stakeholders and parameters, including environment, safety and security, social acceptance and customer expectations. The modelling allows the impact of all competing and complementary new mobility system operational concepts to be assessed, compared and understood. For the aviation sector it includes the full spectrum of air vehicles: large civil transports, UAVs, personal aviation, rotorcraft, compound rotorcraft, tilt-rotors, etc., as well as all aerial activities, transport and non-transport.

This modelling also allows an effective and efficient validation of the whole air transport system infrastructure, covering aircraft, airport and information, communications, navigation, surveillance (ICNS) and air traffic management (ATM). This verifies that innovative products can be integrated beneficially into the overall transport system.

1.4.4 MOBILITY SYSTEM DESIGN

An architectural representation of the total transport system is available with aviation at its core. This architecture sets the context and boundaries for aviation and other transport modes, their integration and each mode’s contribution. It is built on a level playing field vis-à-vis cost and environmental assessment, taxation, regulatory burden, public subsidy, etc. The architecture enables a holistic, end-to-end system analysis of the entire transport system taking the whole-journey view. It also covers the intermodal integration of information systems in a competitive environment and takes into account natural and statutory monopolies, and global as well as European aspects.

There is an intermodal network design for seamless end-to-end journeys for passengers, baggage and cargo. The design accounts for the entire diversity of air vehicles as well as modal shift and its associated implications. It balances public service obligations, especially to remote
and peripheral regions, with competition and market requirements. It has the capability to evolve over time to account for changing conditions in the real world such as demographic shifts and urbanisation. **Interoperability requirements and standards** enable integration to develop a truly multimodal system, facilitating both evolving information exchange across modes and trans-modal scheduling and ticketing.

The design enables total transport system **optimisation and resilience** including dynamic reconfiguration in the case of demand fluctuation and unforeseen incidents. The requirements to ensure mobility under abnormal conditions, including public service needs, are fully understood. Multimodal alternatives are defined based on a combination of multiple networks (air, rail, road, public transport both at origin and destination) to meet these requirements. Agreed methods are available to ensure proper local optimisation of transport infrastructure and ensure buffers in order to provide resilience. The costs of this resilience within the intermodal system are understood, accepted and shared.

### 1.4.5 MOBILITY SYSTEM PERFORMANCE

A model is available which allows detailed analysis and forecast of mobility flows and journey performance. This model is also capable of evaluating the qualitative and quantitative contributions of different transportation modes, concepts and infrastructures to European mobility goals in a door-to-door mobility environment.

A **performance baseline** is defined for the mobility system based on the four hour door-to-door goal. Progress towards its achievement is forecast, measured and validated.

**Infrastructure network planning** takes into consideration co-modal needs and expectations. Planning identifies and overcomes bottlenecks, ensuring connectivity at affordable costs. **Infrastructure planning** and progress monitoring is based on a well-defined methodology, tools and metrics for **assessment of the potential contribution of transport modes and infrastructure, services and new concepts**. Infrastructure capacity, utilisation, efficiency and performance baselining are supported. The capability is available to perform future scenario-based assessments.

The **classification of transportation infrastructure nodes and services** offered by different transport modes is based in an agreed and accepted methodology. This is used to identify the importance of the nodes within the total transport system based on their local and regional economic contribution; quantified passenger and cargo demand characteristics and levels; and the level of intermodal integration.

The delivery of the transport system and associated services is monitored using **customer-oriented performance metrics** with particular attention paid to **customer-satisfaction metrics**. The performance of transport systems and the contribution of the aviation sector to European mobility is monitored, assessed and published. Evaluations are made of the contribution of the aviation sector to: reducing journey times, to increasing frequency and punctuality, and to decreasing the costs and risks of the complete transport chain. The assessment also determines the accessibility of the entire population of the total transport system, including variations depending on location.

The **ability of the ATS and infrastructure to manage mobility needs** is evaluated on an evolving basis using trend and sensitivity analysis.
1.5 Travel process management

1.5.1 TRAVEL MANAGEMENT TOOLS

An improved means to manage the travel process is essential. Travel is managed using a customer travel management tool capable of delivering robust, relevant and complete travel choice information to customers before and during a journey. An advanced intermodal journey planning engine powers all customer-facing planning, pricing and shopping tools.

There is well-defined accountability, responsibility and cost allocation (including compensation obligations) between the different stakeholders. This is invisible to the customer and is perceived as a single accountability.

The travel management tool is built on a number of components.

Planning: The intermodal/multi-modal journey planning tool enables unbiased address-to-address, intermodal itineraries that meet customer needs to be built across multiple transport modes and operators/service providers. Common definitions, interfaces and data sources ensure interoperability. An intermodal journey pricing and total trip cost assessment tool allows the customer to evaluate, compare and contrast the quality/service level, prices and costs of individual trip segments as well as the overall trip. Options can be ranked according to customer-defined criteria using a journey recommendation engine that also delivers recommendations or advice en-route based on real-time operational data. These data include collaborative/user-generated data (e.g. sensors, collected mobile global navigation satellite system (GNSS) data) and user-generated advice describing the specific environment of the actual journey.

Shopping/booking: Next, an intermodal shopping tool enables customers to compare sets of end-to-end intermodal travel solutions. Search parameters are specified by the requestor, e.g. total cost, travel dates, preferred transport modes and quality of service. The journey is booked using an intermodal reservations/booking facility supporting automatic reservation of all purchasable/bookable segments of the overall journey in a single transaction. Subsequently, an intermodal/multimodal ticketing tool issues single or multiple tickets and tracks the sale and usage of the complete journey as well as the individual segments. This is based on a common ticket.

Paying: Payment can be made through a common-use, customer-facing intermodal/multimodal trip payment tool. This enables a single payment for the full intermodal trip through a seamless connection with all relevant merchant’s processing platforms for billing, settlement and accounting purpose.

On-the-move: To maximise flexibility and choice, en-route or immediately before departure, the traveller has access to on-the-go mobile ticketing for local/public transport to purchase local/last-mile portions of the journey (e.g. local/commuter rail, public transit, local buses). This is based on a common European standard. En-route,
intermodal trip management and servicing enables the (self-)servicing of the entire trip (e.g. cancellation, rebooking, voluntary changes, purchase of ancillary services and add-ons). This is usable by all travellers at all stages of the journey.

**Storing preferences:** An intermodal travel dossier/total trip record containing all trip elements is used for storage and management of unique travel dossiers. Passenger preferences are open to all operators but are privacy-assured.

### 1.5.2 ASSESSMENT OF MOBILITY CHOICES

Customer travel choices are supported by the travel management tool, underpinned by sound and transparent logic that is based on a set of *metrics for comparison of different transport modes* according to relevant customer-based criteria. The criteria are integrated into a total-impact model that uses standard assessment methodologies and outputs easy-to-understand indicators from a *tool for fair and unbiased assessment*. This tool uses accepted standards for multi-criteria assessment.

### 1.5.3 INFORMATION SYSTEMS FOR INTERMODAL MOBILITY CHOICES

Mobility choices are underpinned by an application for pre- and in-journey decision-making across all modes of transport. The information system is built on the *sourcing, integration, distribution and storage of real-time data* using all available sensors, including the customers themselves, from all modes of transport. Cross-provider data interchange standards are available for service data and real-time operational data. Privacy-assured, customer generated data is used in journey planning engines and customer facing applications.

**Real-time transport service display** and tracking and itinerary guidance is available at all stages of the journey, indoors or outdoors. This is supported by *multi-channel notification* capabilities and systems that ensure relevant, timely and personalised information is sent to the passengers at all stages of the travel process. Notification is made using robust, high-speed and secure *in-journey communication links*. These links support business and leisure applications at all stages of the journey. Interoperability is an essential prerequisite.

### 1.5.4 DISRUPTION AND RECOVERY MANAGEMENT

Disruption management and recovery mechanisms are available to respond to any journey disruption and to provide ongoing support to the customer, whose rights and interests are protected. Journey options can be taken into account before disruptive events occur, thereby optimising passenger and freight operator choices.

A *journey monitoring and disruption detection* function is available from pre-departure to arrival. Intelligent journey planning tools automatically identify any issue with the current route and suggest an alternative. The current travel contract is honoured by the new sector service provider and allocated costs are automatically re-distributed. An automatic *customer notification* function makes the customer aware of any disruption.
potentially impacting the journey. In the case of any event impacting on the original itinerary, real-time alternative intermodal journey recommendations are made to the customer supported by automatic disruption handling and processing whereby the customer can accept a proposed alternative route. Cancellations, re-bookings, refunds and compensation are processed automatically.

Disruption management is supported through legislation and service levels that create a level-playing field for all relevant modes of transport in terms of common passenger rights. Existing legislation is updated taking into account the intermodal and door-to-door nature of the travel environment.

1.5.5 CRISIS MANAGEMENT AND CONTINGENCY PLANNING

Crisis management and contingency planning are strongly linked to disruption management, and are based on an agreed framework for the actions to be taken during crisis situations. The framework covers the protection and support that will be provided to customers and how recovery will be managed and implemented. Mobility plans to ensure service continuity are defined for all known or envisaged types of large-scale disruptive events. These plans address prioritisation of available capacity as well as cooperation between infrastructure managers, operators, national authorities and neighbouring countries. The plans also define freedoms or obligations for the temporary adoption or relaxation of specific rules to manage crises. In addition, collaborative mechanisms to enforce mobility plans are agreed and applied in times of disruptive events and for the subsequent recovery to normal operations.
1.6 Aviation

1.6.1 FROM AIRPORTS TO AIR TRANSPORT INTERFACE NODES

Air transport interface nodes are the movement areas used by all kinds of air vehicle. These include airports, vertiports and any other ground configuration supporting air vehicle and passenger services, as well as the infrastructure associated with the integration of air and other transport modes. The right standard and quantity of nodes are needed at the right locations to support the Flightpath 2050 goals – particularly the need to accommodate 25 million flights per year, to ensure a four hour door-to-door journey and to ensure that flights arrive within one minute of the planned arrival time.

In these nodes, optimised processes for passenger, baggage and freight handling are applied. This is defined in terms of metrics such as punctuality and delay, seamlessness, convenience, availability of information and predictability. Consequently there is a strong link to the effectiveness of the management of air traffic as well as to the achievement of overall mobility goals. Optimisation is based on the analysis of logistics processes across the entire airport system. This includes nodal (airport) system modelling and simulation using representative scenarios and operational case studies. The analysis, modelling and simulation use operational data capture and mining and generate a set of standard outputs covering the ACARE target areas. Total node (airport) management is based on collaborative decision making processes to create seamless and specific passenger and cargo procedures, techniques, concepts and performance metrics.

In addition to process optimisation, there is also improved air transport interface node (airport) design delivering the best possible infrastructure layouts, airside and landside. There is also a new vision of services resulting in a positive travel experience. The vision is focused on the reduction of wasted time and higher predictability for essential customer services through better guidance and information; and improved passenger offers (entertainment, leisure and business applications, technology and facilities).

The nodes are fully integrated with other transport modes for passengers, baggage and freight. Integration occurs at all levels starting with the design of intermodal networks, processes and the required infrastructure. Comfortable and efficient access to the air transport interface node is delivered through innovative approaches to safe, efficient, frequent and stress-free transport services. These are based on new transport concepts including the minimisation of the impact of road accessibility (traffic, parking) and maritime accessibility for off-shore capabilities.

Airside, there is a collaborative approach to the integration of new air vehicles and aviation technology into existing ground node infrastructure and processes. New ground node infrastructure and processes are developed where this integration is not feasible.

Europe’s air transport interface nodes are recognised as leading the world in customer service, satisfaction as well as operational efficiency and Europe has a strong export business to develop this model for other regions of the world.
1.6.2 INFORMATION PLATFORM FOR OPERATIONS

Adequate information, communication, navigation and surveillance (ICnS) infrastructure is essential to support new service provision concepts. This is delivered through new concepts for information and communications infrastructure. ICnS is integrated to address co-modality between air transport and other transport modes. The infrastructure meets all performance (safety, data capacity, quality of service, data security, etc.) requirements to enable the provision of services for all types or air vehicle and range of missions as well as supporting the customer’s whole journey view. ICnS infrastructure is optimised and managed in the most cost effective manner.

A new air vehicle information management network is based on the further development of the system-wide information management (SWIM) concept. Skills and support tools assure the maintenance of both legacy and new critical infrastructure.

Information services are decoupled from physical channels and based on information network architectures that expedite development of innovative services and facilitate market access to new entrants. Very high quality information is made possible using consistent data derived from independent data sources. These sources include operational data and open data stores that integrate and fuse all appropriate data derived from and distributed to the ground and the air. Communication (voice and data) and information exchange channels are efficient in their use of radio spectrum. Adequate connectivity, bandwidth and channel throughput ensure the integration of the air vehicle into the overall information management system. Cyber security is assured and privacy is adequately protected.

A performance based navigation and surveillance information platform is available throughout the whole network meeting the needs of future operations. This exploits off-the-shelf technologies as far as practicable. It includes both navigation technology enabling flexible and sustainable operations and sensor technologies to enable all weather operations and avoid atmospheric hazards. A complementary navigation input to GNSS is provided to overcome vulnerability concerns. UAV aerial applications ensure low cost ICnS capabilities with global coverage and are robust to the failure of individual components. GNSS is developed. Other developments include enhanced and synthetic vision, electronic countermeasures against jamming, spoofing and other security threats.

Continuous availability of accurate air vehicle position information for surveillance applications is achieved through new operational procedures and technical surveillance systems. These applications include search and rescue, surveillance for UAV, and other automated monitoring and security operations. Innovative independent non-cooperative surveillance systems (e.g. multi-static primary radar) enable the system-wide use of secure satellite surveillance. There is secure integration of different co-operative and non-cooperative surveillance technologies as well as fusion of presence and location information from disparate sources.

Competent, global standardisation bodies ensure the timely development of global airworthiness and interoperability standards following formalised processes. Standard development is fully synchronised with the development of technical solutions.

1.6.3 MANAGEMENT OF AIR TRAFFIC

New or improved air traffic management/control services are delivered to aviation. These range from the strategic or information level to tactical intervention (including search and rescue). They are built on the
success of and complement SESAR. Provision of innovative and competitive services to airspace users is facilitated by new concepts and legislative measures and supported by the appropriate governance, institutional and economic framework to facilitate, regulate and oversee the total transport system.

**Incentive mechanisms** promote the adoption of the most appropriate technologies for airspace usage supported by a new charging mechanism that has replaced the current International Civil Aviation Organization (ICAO) based weight dependent scheme. Worldwide legislative measures enable the best equipped - best served market oriented mechanism and support new business models for the provision of services to airspace users and the management ICNS infrastructure.

The prioritised integration of air traffic management (ATM) in the overall aviation chain is supported. This ensures that the research performed is fully consistent with and targeted to relevant aviation developments. This includes integration of ground and airborne capabilities, global interoperability and standardisation frameworks. The associated regulatory and institutional frameworks are adaptable to future market needs.

**New operational concepts and aviation services** are developed to enable a high performance agile and resilient system, able to manage 25 million commercial flights a year safely arriving within one minute of the planned arrival time. All vehicle missions and aerial applications are catered for and integrated. The impact of weather and other disruptions is mitigated. Performance-based operations allow each aircraft to fly the most direct routine and efficient flight profile with very low delays. Safe separation is maintained using advanced avionics capabilities and the most appropriate ICNS technologies. Operator productivity is increased through new operating paradigms, increased automation, innovative services and uniform application of best practices. Fully integrated collaborative decision-making is applied to all phases of flight encompassing all airspace stakeholders (airlines, air vehicle operators, military, air traffic control and airports). This balances and prioritises stakeholder interests, based on analysis, trading rules and assistance tools.

Breakthrough technologies and operations are emerging. These include intelligent self-separating air vehicles; swarm-type operations for high density en-route and departure/arrival or cooperative optimisation and separation of air vehicles in-flight. Atmospheric hazard avoidance is available and includes self-separation in a mixed environment.

There is strong demand for the services delivered by European aviation service providers both from other transport sectors as well as from other parts of the world. **European service models are being exported** and exploited by others, ensuring a dominant market presence and profitability for European service providers across the mobility domain.

At the network level, congestion management and network recovery mechanisms are identified and implemented across the network. Network-wide optimisation is applied to all vehicles ensuring the best trade-off between the necessary performance criteria.

Quantitative performance requirements are used in conjunction with an ability to adapt and tailor air vehicle operation, fleet operation and flows. Global criteria are available for runway and taxiway configuration and prioritisation based on, for example, best-equipped-best-served or on-time-first-served rules. Frequent procedures change management is applied, using rapidly changing trade-offs of performance criteria (e.g. environment: noise vs. emission, flight-efficiency, and capacity). This change management
process is supported by system flexibility and operators’ training and skills. On the airfield, effective airport airside operation modelling tools allow multidisciplinary optimisation of airport airside operations by trading off noise, emissions and capacity effects in the development of new technologies and procedures.

**1.6.4 SYSTEM INTELLIGENCE**

System intelligence provides automation support to aviation ranging from support to humans through to complete automation where appropriate. It has applications in mission management, air vehicle operations, air transport interface node operations, travel and traffic management, transport network management, air vehicle maintenance, decision-making support, crisis management and traveller assistance. It is based on a full understanding of the human factors implications (see Challenge 4) of decision support systems and automation. The application of system intelligence is supported by regulation for human-centred automation. This regulation defines authority-sharing between different actors (pilot, controller, and machine). It addresses liability, covers training and qualification rules, certification/qualification of new systems, and software development.

**Intelligent technologies** including automated and intelligent systems are applied. These ensure that safety systems are decoupled from human error, are adapted to individual human performance, and provide explanations of machine decisions.

Autonomous/automated operational concepts, systems and interfaces are developed and operated. These address, for example, certification and responsibility issues (e.g. UAVs including operating in non-segregated areas), automated air-ground communication for integrated decision-making, unknown/unspecified problem solving by the human or the machine, and fail-back procedures in the case of automation or communication failure.

All of system intelligence is underpinned by enhanced software resilience and agility to cope with fast change or different system configurations (airspace, airport, priority, resilience, etc., see Challenge 4).

The following figure provides an illustration of the high-level evolution of the capabilities needed to meet the goals of Challenge 1. SRIA Volume 2 provides more detailed information on evolution of the enablers, capabilities and technologies needed to meet this Challenge as well as the metrics used for monitoring progress.
1.7 Timeline

2020

Customer-centric mobility
- Evolution of customer mobility expectation and profile understood
- Market & societal opportunities and acceptance factors known
- Customer-centric mobility system design
- Planning, payment and single ticketing support for intermodal journey selection
- Seamless transport processes defined
- Legal framework for data privacy and availability

Integrated transport
- Aviation at core of integration of transport modes
- Level playing field for all modes of transport
- Intermodal business models incentivise seamless travel integration
- Mobility performance baselined
- Intermodal transport architecture & standards
- Interoperability data-sharing regulation
- Collaboration on implementation & context at early stages of research

Aviation services
- Design of innovative passenger, baggage and freight processes
- Integration of new air vehicles and services at airports
- Advanced ATM functions introduced
- Concepts to reduce impact of weather on air transport performance
- Improved disruption management & recovery
• Accountable door-to-door integrated journey planning, payment and single ticketing used for the majority of journeys
• Automatic journey monitoring and disruption management for the majority of journeys
• Seamless processes implemented
• Indoor and outdoor route guidance
• Robust, high-speed and secure personal communication and notifications links

2035

• Infrastructure planning and prioritisation based on contribution to mobility goal
• Choices of transport modes based on fair and unbiased comparison
• Resilient behaviour of the Air Transport Sociotechnical System and supporting policies in place
• Strategic, tactical and real-time mobility modelling and simulation with forecasting functionality for integrated transport system
• Mobility plans for large-scale disruptions
• Optimised processes and interfaces between transport modes

2050

• Fully integrated intermodal transport system
• Mobility goals achieved
• Various innovative mobility systems and services complementing each other based on their individual contribution
• Infrastructure development in line with mobility needs

• Innovative air vehicles and services fully integrated
• Performance-based ICNS information platform
• Optimised ATM services based on breakthrough ICNS technologies and services
• Optimised airport infrastructure
• Innovative services to airspace users

• Flights arriving within +/-1 minute of planned time
• Win-win situation between aviation infrastructure and neighbours
• Sustainable aviation ground infrastructure and operation
• No congestion due to capacity shortfalls
Challenge 2

Maintaining and extending industrial leadership
Over the past 40 years, European aviation has successfully risen to the top of the world rankings, through the combined, coordinated and collective efforts of many European entities, both public and private, major companies, thousands of small and medium-sized enterprises (SMEs), academia and research laboratories. Together they contribute to the global reach and success of European aviation. In the recent turbulent times, since September 2001, aviation has persisted as one of Europe’s strongest economic sectors.

The creation of the Internal Market for Air Transport in 1992 removed barriers to entry and led to the creation of low cost carriers, which have proved their right of existence with a market share in Europe of 41%. As network airlines were unable to merge with or acquire non-EU partners, they established alliances. These alliances have worked efficiently, offering a wide range of travel options to passengers and giving airlines the necessary economies of scale. At the same time, Open Skies agreements came into existence, first on a bilateral basis, soon followed by the European Commission negotiating Air Transport Agreements with third countries on behalf of Member States, the EU-US Agreement being the most significant. These agreements facilitate further market opening coupled with a close alignment of regulations in terms of security, environment, safety, competition, etc.

However, competition is becoming ever more fierce not only from established competitors, such as the United States, but from recently emerged and emerging challengers, such as Brazil, Canada, China, India, the Gulf States and Russia. The authorities in 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 concepts, technologies and systems, but also by developing an adequate policy framework. Financial and human resources are abundantly available in the emerging competing regions and Europe must increase and focus its resources carefully to avoid being swamped within the timeframe of Flightpath 2050.

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 and even increased investment in the technologies of tomorrow, as on one hand, the market demands shorter cycles of new technology integration and, on the other hand, competitors enter the market with an aggressive approach on prices.
By 2050, the innovative and sustainable European aviation industry has cemented its place as a key contributor to ensuring economic well-being, generating wealth and extending Europe’s influence in a globalised and highly competitive world. This is recognised by decision makers, industry stakeholders and society as a whole resulting in their alignment behind the common goal to enable continued European industrial leadership. Innovation is focused on serving the passengers’ needs as well as those of freight operators and non-transport services, such as maintenance, repair and overhaul (MRO), air traffic management (ATM) and airport services.

As a result of an on-going development process, the strategic role of the aviation industry is widely understood. Europe’s industry maintains its critical mass of leading edge capabilities and competitiveness through continuous and focused investment funded by strategic partnerships of the private and public sectors. Risks are shared as appropriate. Europe retains the key functions of design and manufacturing. The European aviation industry is prestigious and viewed as a highly desirable, attractive, challenging and rewarding career choice. The availability of a resource pool of highly educated, skilled personnel is assured despite stiff competition from other parts of the world and other industries. Employee retention in the sector is high but employment is flexible allowing cross-fertilisation and exchange of employees, ideas, lessons learnt and best practice.

Europe’s industry is innovative and competitive, developing and delivering high quality products quickly and efficiently meeting time-critical market demands. Products and services are developed and tailored to meet ever-more rapidly evolving and stringent requirements. Time from concept to market is minimised both by improvements to the industrial process – design, test and validation, certification, manufacture – and also by streamlining the administration associated with the use of public funds in collaborative research programmes. The continuity between basic research, applied research, development, manufacturing and products and services has been strengthened.

New concepts are realised by a combination of strong technology pull generated by market needs combined with the strong technology push generated by a vibrant and successful industry. Future challenges are addressed by integrating technologies within a systems and services concept that supports the whole air transport system.

Design, manufacturing processes and support tools are state-of-the-art and continuously improved and upgraded. Multi-disciplinary design and accurate development tools are used routinely. Balanced design techniques ensure that performance prediction for any parameter is achieved within a very fine tolerance in the final product. Integration has reached very high levels, ranging from the integral embedding of systems in the vehicle to the integration of vehicles as active nodes in the infrastructure. This integration is designed, developed, implemented and operated successfully by applying a system-of-systems approach, along with risk mitigation techniques. Development, validation and integration of disruptive, step-change tech-
nologies are supported by modelling and simulation, and ultimately leading to less prototyping, ground and in-flight testing.

**Europe drives global standardisation** covering all elements of the industry – materials, structures, manufacturing, systems, operations, maintenance – across all domains – safety, security, environment – through the entire life cycle from design through to disposal. In particular, certification processes are harmonised worldwide with Europe playing a leading role in the harmonisation process. The European certification process itself has been streamlined, reducing complexity and cost. Certification based on virtual reality is widely applied at both component and product level.

**The Maintenance, Repair and Overhaul (MRO) sector is well recognised** as an important economic sector and has a strong global position. The maintenance of European as well as non-European based airlines can be performed on sound economic conditions within the European Union. Manufacturing and services are underpinned by **partnerships between manufacturers, airlines, MRO operators, airports, and air navigation service providers (ANSPs)** working together and collaborating with other modes to deliver the products and services demanded by the market. In particular, there are alliances to optimise services and infrastructure. Different modes of transport are integrated from the customer perspective. This results in a seamless European transport system that serves individual mobility needs and provides a choice of travel options according to customer preferences (see Challenge 1). European carriers play a leading role on the global stage ensuring that networks are structured to serve European markets. The removal of ownership restrictions allows the further integration of air transport operators. In addition, intellectual property rights and knowledge are protected, resulting in the establishment of global partnerships without the risk that current collaborators become future competitors.

Innovation is supported by a strong, coherent European research network and partnerships between the relevant private and public actors, including industry, research institutes, universities and government (see also Challenge 5). Appropriate levels of private and public funding will have been made available. Formal institutional arrangements, based on public-private-partnerships (PPPs) and joint technology initiatives (JTIs) have been established based on lessons learnt from Galileo, SESAR and Clean Sky.

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**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 retain 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.
2.3 The enablers to reach the goals of Flightpath 2050 for Challenge 2

Enablers describe what is needed to achieve the goals. Capabilities describe how the goal can be achieved. The general enablers needed to realise the goals associated with Challenge 2 are as follows.

• The development of technology, its demonstration and flight test: Aviation vehicles and air transport systems are sophisticated and technologically complex, with ever increasing levels of integration. Before a new technology is safely introduced into an aviation product it must undergo rigorous verification and validation. This is achieved by a combination of modelling, simulation, ground testing, such as wind tunnel testing, and flight testing. A new technology, or combination of technologies, could require final testing in an environment close to operations and at full scale, so demonstration and in-flight testing at system level remain essential means to manage these high level risks in the innovation process.

• An efficient development and manufacturing process: The typical development process for an air vehicle, which embeds the results of research into innovative products, engages hundreds of organisations and thousands of individual participants over many years. Greater efficiency in these processes facilitates faster and more frequent introduction of innovative products. To secure this efficiency a seamless integration of design and manufacturing capabilities has been achieved routinely and cooperatively between the stakeholders throughout the whole supply chain.

• Continued and focussed investment: Europe’s industry ensures that it maintains its critical mass, and improves its leading-edge capabilities and competitiveness through continuous and focused investments in technology research and innovation. The timeframes for these investments are very long-term, typically decades. Europe’s industry is recognised globally for its manufacturing, vehicles, engines, services, airports and a large range of very cost effective and energy efficient products.

• The definition of regulations and standards to create a global level playing field: A fair and balanced set of regulations and standards has been put in place, which facilitates European aeronautical and air transport leadership and consolidation in the global marketplace.

• Innovative business models, regulations and incentives to accelerate innovation: A strong and seamless research and innovation supply chain provides a swift and smooth advancement of high-potential innovative ideas to marketable products. Mechanisms are in place that manage the development risk of breakthrough technologies. Small- and medium-sized companies are valuable partners in long-term, strategic research and innovation initiatives. They have affordable access to test facilities to develop and demonstrate innovative technologies (see also Challenge 5). Close cooperation between systems manufacturers and small- and medium-sized companies ensures rapid, widespread application of new technologies as well as a fair share of risks and revenues.
- **Efficient certification of aviation products:** The European certification process is streamlined, efficient and low cost. It is widely applied at component, product and system levels, and capable to anticipate and adapt to new technologies in the future.
The development of a broad range of vehicle technologies continues to be required to provide the basis of the most innovative, competitive and environmentally friendly aviation products. The environmental goals described in Flightpath 2050 cannot be achieved by simply incrementally enhancing aircraft architectures. Significant performance improvement requires step changes in technology and architecture. The associated research and innovation is performed by original equipment manufacturers (OEMs) and their supply chain sharing the burden of risks appropriately.

Airframe technologies deliver advanced, aerodynamic vehicle configurations; improved flow and load control (including laminar flow); and, optimised structural designs. New materials and processes are exploited to create lightweight structures. There are new vehicle shapes and innovative configurations that realise the potential for novel power plant integration and active aircraft control.

New emerging rotorcraft configurations such as compound helicopters and tilt-rotors are available in the short to medium-term. They offer the potential for improved range and speed. New missions that exploit short/vertical take-off and landing (SVTOL) flight are possible. These include, for example, extended search and rescue and point-to-point transport missions. These new aircraft contribute significantly to meeting the four hour door-to-door target set by Flightpath 2050.

Improved performance of power plant and propulsion technology is a continuing theme for research and innovation. Emerging technologies, such as lean burn combustors, geared turbo fans or contra-rotating open rotors, are refined, resulting in optimised performance. New technologies enable innovative propulsion systems, with the potential to exploit novel combustion cycles, ultra-high bypass ratio (UHBR) configurations and the potential of hybrid electric/thermodynamic systems.

Innovative aviation systems and equipment continue to exploit advances made in information systems and communications technology (ICT) to deliver new services, improve efficiency and reduce cost. The optimisation of individual systems continues in parallel with the integration of systems into the airframe. Step-changes in architecture are enabled by new generations of equipment. These step-changes include the more electrical aircraft, optimised energy management, novel control concepts and interconnectivity. There is a trend to increasingly cognisant
aircraft, exploiting sensor technology with specific on-board sensors for surveillance and situational awareness that supports significant improvements in the operational performance of the fleet.

Commercial off-the-shelf (COTS) products continue to influence the design of the **cockpit and the man-machine** interface, to reduce crew workload and to enable a high level of automation. Novel mission optimisation, anticipation functions, and adaptive interfaces provide enhanced environment representation. Vehicle systems technology permits flight which is optimal in all traffic and weather conditions. The exploitation of ICT technologies dramatically enhances communications with ground stations and other aircraft, supporting an accurate and reliable navigation capability.

In **core avionics** a large range of cost effective technologies, such as wireless avionics, multi-core processing and data security, are exploited in the short-term. Research delivers new reliable, resilient and highly distributed technologies which are embedded and certified in core avionics, to provide the extensive computing power needed within the vehicle for its interaction with the overall transport system.

**Cabin and cargo** functions have the most direct impact on the flying traveller, and also have the potential for more frequent upgrade or renewal. These factors combine to make this an area of high value for vehicle operators and of high potential for technological and operational improvements. Customer expectations are influenced by general consumer trends and by their experiences on other modes of transport. Technology innovation keeps pace with these expectations for products to remain competitive, even with the additional constraint of being implemented in a highly regulated environment. In-flight to ground or satellite communication, wireless infrastructure and intelligent power are realised in the short-term and are followed in the medium-term by modular cabins; enhanced cargo handling; flexible cabin configurations; and an enhanced virtual passenger environment.

**Unmanned air systems** are exploited in a variety of civil missions and markets because the regulatory environment has developed in parallel to these new technologies.
An efficient development and manufacturing process ensures that competitive products are delivered to market as quickly, efficiently and effectively as possible. This capability ensures that Europe leads the world for high technology products along the entire supply chain. The unique capabilities of the European supply chain means that it not only feeds European manufacturing but also provides international markets with capabilities that are not available from other sources.

The improved manufacturing capability and assembly process delivers integrated vehicle designs and supports the introduction of new materials for weight reduction. Process development for new materials ensures that manufacturing and assembly are commercially feasible, robust and facilitate increased levels of automation in manufacturing. To deliver weight optimised vehicle designs, increased coupling of different types of materials with significantly different properties is enabled through extensive efforts in the science and technology of interfaces.

Ultimately, there is a fully-coupled manufacturing process, simulation and shop-floor data analysis to optimise manufacturing performance. The realisation of these highly efficient manufacturing processes is supported by continuous and focused investment in highly complex advanced manufacturing technology and systems. In the medium-term, there is follow-on (private) investment in new facilities and the EU supply chain, potentially enabled using other mechanisms such as the European Investment Bank (EIB), European Investment Fund (EIF) and the European Bank for Reconstruction and Development (EBRD). Also in the medium-term, incentive rates are increased at time of high investments needs and European industry is prepared for the entry of new competitors. The growth of manufacturing research centres is sustained.

Research identifies and improves the key facets of an efficient trans-continental product development process, crossing international boundaries, business cultures and time-zones. This enhances the capability of European OEMs to manage the contributions of their supply chain in Europe and beyond. The advanced capability of the supply chain in Europe enables business to be gained from OEMs that are not based in Europe.

Novel manufacturing and assembly techniques, which make optimum use of novel materials, processes and technologies, result in significantly improved manufacturing capabilities. Their implementation is tested, validated and optimised by simulation and technology demonstration, mirroring the product design process prior to full-scale application. Driven by the scale of industrial investments required throughout the aviation supply chain, scientific approaches are adopted to secure capable and reliable manufacturing capacity that can be adapted to demands over the full life-time of the products. Flexibility of application and capacity is a continuing requirement, to reduce manufacturing costs. Technologies which enhance flexibility are in high demand. The potential for self-organising or
product-independent assembly systems is accomplished. In the short-term, assembly processes using component as-measured data to optimise key performance drivers are in place. In the medium-term equipment performance is functionally optimised and in the long-term equipment performance optimally is tailored to service needs at assembly.

Innovative Maintenance Repair and Overhaul is focused on monitoring, diagnostic and prognostic elements for all aircraft systems, including aircraft structures. Advanced health monitoring is supported by automatic communication to ground crews for just-in-time conditioned-based maintenance. Ultimately, self-assessing aircraft have fully integrated health systems. Automation in maintenance processes is increased, the exchange of technical data is optimised and modular certification allows for obsolescence and upgrade. This ‘extended enterprise’ approach for maintenance allows to reduce cost of ownership (including maintainability) and to develop repair strategies for high cost elements.

The high dependence on materials availability, notably for generative manufacturing processes, is off-set by the increased use of recycling to recover rare materials. Research has delivered alternative and equivalent materials and the development of additive manufacturing processes.

A European virtual product strategy is established, through R&D projects, multi-disciplinary optimisation and virtual certification. This creates a collaborative environment for the entire aviation supply chain, including EASA as the safety regulator, and customers. Time to market and product development costs are minimised in a properly functioning market. Ultimately this provides the European aerospace industry with a virtual product as standard practice.

Enhanced high-fidelity modelling of aircraft physics and manufacturing physics capabilities are established compatible with the technology intended to be integrated in future products. Highly accurate models are available in the short-term. The modelling capability includes multi-objective, mixed integer, non-linear design optimisation tool development. The modelling capability is subsequently enhanced to be robust against innovative configurations and radical new solutions in the medium-term.

Manufacturing processes for structures, components and systems are optimised in terms of environmental impact. Energy usage is decreased through improved curing processes, use of less energy and water in corrosion protection processes, etc. The use of recycled materials is increased where; in particular, qualified processes to use reclaimed fibres in composite structures are applied. There is increased usage of bio-materials and there is a decrease in the usage of scarce materials, for which alternates have been identified and qualified. A global indicator of scarcity is used to prioritise research.
Aviation has very long research and innovation cycles, with return on investment typically occurring many years after initial investments are made. This can be a major disincentive to such investment and results in market failure and disadvantages European industry vis-à-vis competitors where preferential public funding mechanisms are available. Continued and focused investment overcomes this barrier.

The entire aviation value-chain is analysed and understood to promote growth across the entire sector. The service aspects of the value chain are encouraged to grow at a rate of three times the growth rate of rest of sector, whilst maintaining product and service capabilities across the entire aviation sector.

Targeted and specific interventions overcome the issue of market failure and fill the gap between the end of research and the start of development. These interventions are based on a comprehensive understanding of the full aviation value-chain and facilitate growth across the entire sector. The continuation of existing European Framework instruments is essential. Continuity and visibility of funding is enabled by a frequently updated, multi-annual European technology roadmap covering all aspects of aviation. In addition to technology for aviation products, attention is given to manufacturing and operational technologies to assure the long-term competitiveness of European manufacturing industry.

Efficient and dedicated research and technology innovation programmes are organised within a stable multiannual framework that can adapt flexibly to the changing landscape. These programmes acknowledge and support the total transport system/mobility approach but do not neglect the specificities of aviation and the need to retain Europe’s prominent position in the aviation sector. All actors along the supply chain, as well as the public sector, invest at the appropriate point in the research, technology and innovation process.

The contribution of Small and Medium Enterprises (SMEs) is vital to aviation maintaining its prominent position as decisive contributor to European competitiveness and economic wellbeing. SMEs are, therefore, provided with a reliable and secure funding environment which fosters innovation.

The research, technology and innovation pipeline is filled on a rolling basis, to secure a continuous feed of basic research into applied research into technology demonstration into product innovation. The risk of technology failure is an integral part of research, so a critical mass of work is conducted at each stage of the process to enable successful technology candidates to be down-selected for exploitation at the next stage of the process. Activities are allocated appropriately along the innovation chain. Within EU Member States, national research establishments are used to perform basic research activities and to develop breakthrough high risk technologies. A common strategy between Member States is enacted for facilities management and development and, ultimately in the long-term, there is joint operation of strategic facilities, also see Challenge 5.
Positive legal and financial incentives to research and innovation are provided. These include the differentiation of input (cost auditing) and output (value-for-money) measures when evaluating proposals for, and the outcomes of projects and programmes. The administrative burden is reduced through use of a single set of documentation and a standard reporting framework for research and technology projects with public funding across the EU at all levels – European, inter-regional, regional and nations. This alleviates the requirement for multiple audits by full acceptance of results at the national level. Stepped public funding rates that reward success are applied by, for example, retrospectively increasing funding from 50% to 60% if research and technology development (RTD) results in innovative products or services within a given timeframe. Incentive rates are tailored at critical times for RTD and the application of R&D tax credits is harmonised across the EU.

Optimised public-private investment programmes cover the entire supply chain and improve the harmonisation of national programmes in Europe. The potential for conflict and duplication is avoided. These programmes create a positive environment in which stakeholders are encouraged to participate even when confidentiality and protection of intellectual property rights (IPR) are significant concerns. Interests are protected by clarifying the terms under which competitors collaborate; eliminating collaborative programmes with third countries that do not contribute to EU industrial competitiveness; and preventing the access of external competitors to the outcomes of EU RTD by applying strict IPR and confidentiality rules rather than open access in future programmes.

Continuing investment in product technology and services is accompanied by a proportionate investment in industrial technology.
2.7 Definition of regulations and standards to create a global level playing field

Regulations and standards create a global level playing field enabling market access and free and fair competition for Europe’s aviation sector both across the world and across modes.

The global level playing field is facilitated by the inclusion of air transport services in their entirety in the General Agreement in Trade in Services (GATS), including the establishment of a World Trade Organization (WTO) body to address unfair subsidies and facilitate dispute resolution. GATS may also extend to cover CNS/ATM services. This, together with close alignment of industry, providers, EASA and the other relevant agencies, public-private partnerships (PPPs) and joint technology initiatives (JTIs), results in step changes in reduction of time-to-market of CNS/ATM innovations.

A new agreement based on the Large Civil Aircraft agreement between the EU and US from 1992 is concluded on subsidies for the development for civil aircraft, including aircraft in the range of 70-800+ seats. In addition, a common international agreement that also includes regional aircraft is established on rules for trade credit insurances and export financing. All countries with aviation industries are parties to these agreements.

Standardisation and certification are based on close cooperation between research establishments, industry, operators and regulators. In the short-term, new standards are developed in anticipation of emerging, promising technology. In the medium-term the time lag between the technology breakthrough and the development of standards is reduced and in the long-term standardisation activities are performed in parallel to RTD activities.

Regulatory impact assessment enables the adoption of new technologies, business and organisational models, and processes. Also in the regulatory domain, regulators and certification bodies are integrated in the research and innovation process from the beginning to optimise standardisation and certification. They sponsor research on new methods and means for validation and certification, integrating all stakeholders. EASA is integrated into the innovation cycle to speed up certification of innovative technologies. In the short-term, a division
is created within EASA that is involved in the innovation cycle; in the medium- and long-terms EASA, supported by experts in research establishments, provides policy and guidelines on how to certify innovative, low technology readiness level (TRL) technologies and systems.

Successful research and innovation is underpinned by the appropriate legal base for, inter alia: standardisation, validation and certification while ensuring a global, level playing field; development of policy and protection of intellectual property; and the creation and maintenance of a network of national funding agencies and national platforms.

Finally, a mechanism is designed and implemented to measure the achievement of institutional goals (leading to metrics and criteria on achievement of the goals).
2.8 Innovative business models, regulations and incentives to accelerate innovation

In order to achieve the goals set within Flightpath 2050, EU legislation and the applicable regulatory and fiscal/financial framework are streamlined to accelerate the development and to encourage the deployment of technologies that increase the competitiveness of the industry and, in parallel, reduce its environmental impact. Assessing the economic impact of different combinations of controls, incentives and instruments is crucial. The overall objective is to foster innovation in the field of competitive and green technologies and influence stakeholder behaviours to deploy these. In addition, recyclability is incentivised, and the development and deployment of sustainable alternative fuel is assisted.

Progress is defined through the setting of performance-based targets which are appropriate, ambitious, achievable, and measurable. Targets are stand-alone or are incorporated within regulation as required and do not introduce competitive distortions with other sectors and within aviation (level global playing field).

**Metrics** that are appropriate for purpose are used. These metrics reflect the three pillars of sustainability. They also account for socio-economic impact and benefits based on econometric and socio-economic modelling to quantify real impacts (market-based or legislative). They utilise the best available knowledge of aviation climate science for optimised flight planning.

**Reduction of development and certification costs** flow through to lower cost and faster routes to market for key innovations. Costs are reduced through globally harmonised certification standards and processes; the maximum use of equivalence with relevant industrial sectors and technologies; streamlined processes to enable test and demonstration of new technology; and extensive use of advanced simulation tools and virtual design/certification capabilities.

Operators are able to upgrade the installed base continuously and aggressively through **accelerated fleet replacement**. This is facilitated by smart use of limited-life solutions and business approaches allowing and based on life-limited aircraft designs. Business approaches include a facility for trade-back or continuous upgrade and include novel ownership solutions. Extensive use is made of advanced MRO capabilities to upgrade the installed fleet of aircraft with new technologies as they become affordable, including modular approaches within the aircraft as the system.

The appropriate **regulatory framework to promote innovation** and mitigate environmental impacts is in place and its **migration from regional to global measures** is accelerated. This framework includes measures to incentivise the introduction of disruptive technology; to promote improved performance of the ATM system; and to promote environmental mitigation. It is based on the harmonisation of regulatory requirements.
Appropriate funding instruments are used to create sustained and stable/predictable RTD at manageable risk and in volumes needed to accelerate innovation to enable 10-year and possibly 20-year programmes. Definition of these instruments considers the matching of Member State funding to EU level funding. The defence sector is engaged such that European Defence related funding efforts include energy security. Matching of themes/topics and projects to civil aeronautics research is encouraged.

Appropriate tax credits are used to reward innovation investment. Consideration is given to the fiscal treatment of research and technology with tax credits allowing full deduction of staff costs of R&T and progressive tax credits for fleet renewal/investment.

Public procurement opportunities and policies are used appropriately to influence supplier and consumer behaviours, for example by using government procurement to incentivise next generation aircraft and systems (e.g. civil synthetic aperture radar for search and rescue/surveillance/safety and airlift fleets). Public sector buying power is leveraged.

Financial instruments and vehicles/institutions are used to leverage the aviation sector’s willingness to accelerate investment in new technology and fleet roll-over effectively. This approach solves the Export-Import (Ex-Im) Bank and the associated export credit impasse that heavily discriminates against EU carriers. In addition a European Investment Bank (EIB) type facility finances fleet renewal at sovereign rates. A Cash-for-Clunkers fund fleet renewal programme is also in place supporting the active decommissioning of older aircraft through fiscal incentives.

Effective cross-fertilisation occurs with relevant sectors, enables an inflow of promising technology (such as nanomaterials, electronics, power electrics and energy).
2.9 Efficient certification

Advanced methodologies including simulation tools are applied to demonstrate compliance with safety and security requirements at component, product, system, and system-of-systems level, including human, social and technical aspects. This leads to efficiency, shorter time to market and lower costs for new products, services and operations. Improved methodologies are available for standardised approval and licensing.

**EASA** is the leading certification body with processes that are fully recognised worldwide. EASA leads the creation of a new generation of globally-harmonised standards aligned with the aspirations of the European aviation community. These standards are the basis of a single set of certification rules that are applied globally by ICAO. EASA awards globally recognised certificates minimising the need for multiple certifications through bilateral agreements concluded with all major countries. In the short-term, EASA expert resources are available at reasonable cost.

The certification process is time- and cost-efficient and globally accepted. In the short-term, the process is based on the accepted use of tools for automated analysis and design, requirements tracking, data exchange and simulation. A modular approach is applied as far as possible. EASA has full access to all necessary data through a manufacturers’ certification data hub and is involved in the innovation cycle to speed up the certification process. In the medium-term, certification data is exchanged along the whole supply chain and with EASA. In the long-term, European processes are followed worldwide. Efficient modular certification is applied, with processes defined and accepted by EASA. This is used at sub-system level in the medium-term and is applied throughout the entire aircraft supply chain in the long-term.

The harmonisation of Certification and Acceptance processes between military and civil authorities at European level is achieved, for common safety and airworthiness requirements. Today’s national certification processes benefit from common specifications, thereby reducing specific requirements for military applications. In the short-term quality assurance and certification procedures are harmonised across the military. European certification specifications, technical standards and means of compliance are available, managed through a joint military certification authority. In the medium-term civil and military certification rules and specifications are harmonised. Consolidated regulations address the specificities required of commercial and military aircraft and their respective missions. This has resulted in the establishment of a world-leading civil and military European certification agency to assume responsibility for certification and qualification activities directly supporting ICAO.

The virtual environment is an accepted means of compliance. The rules for compliance are defined by EASA and verified through the in-service maintenance regime. The evolution from flight-testing to ground-rig testing is the first step in the process. This is followed by the move to full simulation reducing the need for ground and flight testing.

In the short-term, flight simulations are used to create a fatigue loading environment in ground
testing infrastructures. Research produces an EASA-endorsed worldwide atmospheric model (turbulence, precipitation, lightning, electro-magnetic compatibility (EMC)) and EASA approved definition of six sigma extreme manoeuvres for transport aircraft. For aircraft structures, there is a reduced pyramid of testing. The reduced requirement for tests at sub-element, element and component levels is enabled by comparison with previous validated tests and validated methods of analysis. Other tests for risk mitigation only need to be carried out at the manufacturer’s discretion, resulting in a substantial reduction in certification test costs.

Subsequently, in the medium-term, ground test rigs are driven by real time coupled aircraft aerodynamic/atmosphere models. Icing effects are modelled at millimetre scale to enable certification without flight trials. An in-service maintenance regime is established to verify the long-term effectiveness of the methodology. A modelling capability is available to the UAV sector and a virtual flight test service is provided by an EASA contractor organisation to SME aircraft builders. The only requirement is for full scale test and low level material validation. All other tests to mitigate failure at full scale are only performed at the manufacturer’s discretion. This, together with approaches to reduce the indirect cost impact of regulations on small organisations, results in a further 50% reduction in certification test costs.

Ultimately in the long-term, a fatigue, fracture mechanics/crack propagation model of the complete airframe is coupled with aerodynamic and thermal models eliminating ground test rigs completely. Lightning and electromagnetic compatibility are certificated at airframe level by modelling with reduced full scale testing. Fracture mechanics data and models of materials are approved as the basis the airframe certification as above.

Alternative means of compliance are developed, validated and accepted. Simulation is a fully acceptable means of demonstrating compliance with certification requirements. In the short-term hardware testing at coupon level is replaced with simulations. A streamlined set of validation methods is supported by a regulatory framework for certification by simulation. In the medium-term, hardware testing at sub-assembly level is replaced with simulation and a streamlined set of validation methods used systematically throughout the supply chain. This is harmonised this worldwide. In the long-term, simulation is used for system-of-systems validation and a streamlined, harmonised set of validation methods used systematically throughout the supply, worldwide.

Efficient certification standards are available for autonomous flight. Basic UAV standards are developed in the short-term, EASA adopts UAV certification standards in the medium-term and ICAO adopts UAV certification standards in the long-term.

Flexible systems and processes allow robust rapid update or evolution of certification requirements for emerging technology or other requirements (e.g. open rotor, compound and tilt rotorcraft, UAV, single pilot, complex software and hardware, environmental threats).

There are common systems and processes for certification and approvals. These allow use of emerging technologies (e.g. simulation and modelling) to increase efficiency (e.g. incremental certification of applications) and take into account increased levels of system complexity. In addition, there is a common roadmap between EU and leading aviation countries, leading to international standards for security technologies and processes as well as harmonised approaches, methods and tools for operational safety and security.

Certification officials are appropriately involved in relevant RTD projects at the earliest opportunity. Ultimately projects are performed by co-located regulatory and industry staff.
### 2.10 Timeline

**Policy**
- ICAO establishes worldwide environmental security and safety rules
- Start of process to involve WTO in dispute settlement
- Regulations defined for mandatory introduction of innovations in CNS/ATM system
- ICAO has developed environmental standards for aircraft/engines
- Pan-European military certification standards available

**Technology**
- Simulation as accepted means for civil and military certification
- KET identified up to 2050
- R&I pipeline maintained and expanded
- Competitive research & innovation network established

**Innovation**
- Research and innovation covers the full scope of the vehicle and its operation in the aviation system
- Support for long term and large-scale private & public investments which match to the long innovation cycles in aviation
- High level European demonstrators are used to align the timetable and focus of innovation
- First European X-aircraft available

**2020**
The following figure provides an illustration of the high-level evolution of the capabilities needed to meet the goals of Challenge 2. SRIA Volume 2 provides more detailed information on evolution of the enablers, capabilities and technologies needed to meet this Challenge as well as the metrics used for monitoring progress.

2035

- No ownership restrictions of airlines
- WTO body to deal with dispute settlement is established
- Regulations applied in practice and time-to-market of CNS/ATM innovations halved compared to 2010
- Civil/military certification standards are harmonised

2050

- Chicago Convention is revised
- Air traffic services are covered in GATS (WTO)
- Regulations applied in practice and time to market of CNS/ATM innovations 30% compared to 2010
- Creation of a Pan-European certification agency responsible for military certification

- Virtual design, manufacturing and certification fully implemented
- Advanced manufacturing technologies implemented throughout supply chain

- Recycling is a prominent source of raw material
- Virtual design and simulation reduce certification cost by half

- Efficient and focussed R&I programmes cover the whole process from basic research to full scale demonstration
- Supportive legal and financial incentives reinforce innovation
- Systematic validation of novel technologies at full scale and in flight (European X-aircraft)

- Breakthrough technologies are routinely developed for the aircraft and aviation system, to secure innovative products and services and the competitive position of Europe
Challenge 3

Protecting the environment and the energy supply
Environmental protection is and will continue to be a key driver for the aviation sector. The challenge is to **continuously reduce aviation’s environmental impact** in the face of ever-increasing demand. In many instances, environmental issues and competitive issues are linked, for example, a reduction of fuel burn minimises CO₂ emissions but also reduces costs. The **environmental goals in Flightpath 2050** are aimed at the very ambitious target of building a sustainable ATS for the benefit of Europe. They recognise the need for the aviation industry to make an exceptional effort to reduce its environmental impact considering: global warming, noise nuisance, airport air quality, consumption of fossil fuels, sustainable operations and manufacturing. These goals go far beyond today’s capabilities.

The aviation industry produces around 2% of human-induced CO₂ emissions. This may increase in proportion as other energy consumers move to de-carbonise and as the demand for air transport continues to increase. Based on current understanding, aviation affects climate in three main ways: **emissions of CO₂** that results in positive radiative forcing (warming); **indirect effects of nitrogen oxide (NOₓ)** emissions that are partially balanced between warming and cooling; and formation of **condensation trails and cirrus clouds** whose overall effect is considered to cause warming. The non-CO₂ effects are still poorly understood and carry large uncertainties.

In and around airports, aviation impact in terms of NOₓ emissions and noise is a major and increasing concern. Aircraft, however, are not the only contributor to noise and NOₓ emissions – often the high volumes of traffic from local road systems have a larger effect (especially for NOₓ).

Production and assembly of the components of aviation systems consume energy and raw materials. They also require the use of a variety of chemical processes, that give rise to gaseous emissions as well as liquid and solid wastes. Aviation system operations consume a wide range of chemicals, for cleaning and washing processes, stripping and repainting of air vehicles as well as de-icing of runways and air vehicles. The overall impact of these manufacturing and operational effects must be reduced. End-of-life disposal also impacts the environment meaning that future air vehicle designs must comprehensively address recycling.

Energy consumption is a central issue for commercial aviation and securing a sustainable energy supply to match the expansion of air transport is a major dimension of Flightpath 2050.

The long lead time necessary for the development of radical, new disruptive technologies means that European aviation research must already include low-technology readiness level² (TRL) activities aiming at maturity near 2050.

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² See Annex B on definition of terms for an explanation of TRL levels
Aviation’s licence to grow is delivered by revolutionary green technology solutions and secure sustainable energy supplies. Business models and the regulatory framework are aligned to drive the research and innovation needed to make the solutions operational and deliver the associated benefits.

While Flightpath 2050 sets an overall goal of a 75% reduction in CO₂ emissions per passenger per kilometre (km) over 40 years, targets and baselines for emissions are achieved in the short-, medium- and long-term with contributions from both technologies and operations:

• In the short-term, the ACARE goals set out in SRA 2 for 2020, including a 50% reduction in CO₂ emissions per passenger per km, are pursued and met. Many evolutionary technologies are mature near to their maximum potential and disruptive, breakthrough technologies are included in projects.

• The medium-term goal for 2035 coincides with a significant point in the worldwide aircraft fleet renewal cycle and with a generational step change in technologies in service and operational practices. Disruptive technologies are delivered in advance, by or before 2030, to be included in manufacturers’ projects. The enabling technologies, to deliver the Flightpath 2050 performance levels, are initiated. A detailed technology vision is ready by 2035 so that research and development programmes are set in hand from that point forward to deliver at TRL6 early enough to achieve the 75% CO₂ and 90% NOₓ reduction goals.

• In the long-term, the results of continuous performance evaluation are used to reorient and redefine research activities and to refine the split of goals between domains. This accounts fully for mature evolutionary technologies and for the emergence of disruptive and radically new technologies.

The technological research and innovation priorities needed to reach these targets are defined through the roadmap provided by the SRIA. Cross-fertilisation is optimised with other, related sectors, such as materials, information and communications technology and energy.

European energy policy supports targets for the development, production and distribution of sustainable alternative energy sources for aviation. Concerted European activities ensure that the transfer to evolutionary and revolutionary energy sources is achieved smoothly, without disruptions of supply or competitive disadvantages for European operators.

Enhanced methods and processes facilitate the search for new solutions at system level. In terms of fuel efficiency and climate change, in the short-term, all aviation stakeholders unite in their efforts to develop more efficient aircraft and engines, ranging from retrofits via advanced aerodynamic, structural and engine designs towards radically new aircraft configurations. Better operational and flight management procedures are applied, such as improvement of ATM efficiency even though traffic continues to grow. Improved maintenance technologies prevent degradation of fuel efficiency in ageing aircraft and thus reduce the flying fleet’s emissions.
**Improvements in local air quality** are achieved by addressing NO\textsubscript{x} emissions and fine particulate matter (both also contribute to climate change) through fuel efficiency improvement, enhanced combustion technology and emissions-free taxiing: operated initially without the use of the engines by 2020 and carbon free by 2035.

Aviation’s impact on climate has been investigated through several international and European programmes. **Research has resulted in better understanding of the non-CO\textsubscript{2} contributions to the greenhouse effect including NO\textsubscript{x}, particulates and contrails, and their dependence on operational parameters. The large uncertainties that affect estimations of these different contributions to climate change are reduced.**

The **impact of air transport on local communities**, in terms of factors including noise and air quality, and the global environment is **managed and mitigated** to ensure its acceptance.

At the end of their useful life, air vehicles are disposed of in an environmentally sound manner – **recycling being the first option**. Holistic approaches looking across the whole lifecycle enable optimisation for minimum environmental impact.

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**FLIGHTPATH 2050 GOALS FOR CHALLENGE 3**

1. In 2050 technologies and procedures available allow a **75% reduction in CO\textsubscript{2} emissions** per passenger kilometre to support the Air Transport Action Group (ATAG) target\textsuperscript{3} and a **90% reduction in NO\textsubscript{x} emissions.** The perceived noise emission of flying aircraft is reduced by 65%. These are relative to the capabilities of typical new aircraft in 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.

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\textsuperscript{3} Carbon-neutral growth by 2020 and a 50% net overall CO\textsubscript{2} emission reduction by 2050
3.3 The enablers to reach the goals of Flightpath 2050 for Challenge 3

Enablers describe what is needed to achieve the goals. Capabilities describe how the goal can be achieved. The general enablers needed to realise the goals associated with Challenge 3 are as follows.

- **Dynamic management and allocation of targets, assessment of the results and prioritising research.** The environmental goals in Flightpath 2050 are very challenging – beyond current technological capabilities – and need innovative and radical technological, operational and infrastructure solutions. A new approach starting at the whole system level is needed to define the elements of the future ATS. To support this new approach a set of numerical tools for global evaluation of the environmental impact of the ATS is required, along with target setting and the allocation of the targets to the appropriate components of the system.

- **An extraordinary technological effort is needed to define the air vehicles of the future and to identify and realise comprehensive improvements through a systemic approach to air vehicles, far from the traditional aircraft systems architecture.** This enabler will play a key role in reducing aviation environment impact by addressing overall air vehicle design, overall aircraft systems design, overall propulsive systems design, overall physical design, methods, tools and research infrastructure, environment friendly manufacturing and end-of-life disposal.

- **Improving air operations and traffic management** allowing for short/medium-term traffic growth in Europe. Beyond the Single European Sky’s first achievements, new concepts of air operations are vital for environmental impact mitigation. These will involve increasing numbers of stakeholders, moving from the single aircraft mission to aggregated multi-segment travel.

- **Improving the airport environment.** The airport, which is at the heart of an intermodal transport system, must deliver a transport service meeting society’s needs while mitigating its environmental impacts. It is essential to ensure that the net effect from aviation is seen as a positive contribution and benefit to the group of the society situated around the airport.

- **Providing aviation with the necessary quantity of affordable alternative energy sources.** Commercial aviation will depend on liquid hydrocarbons for at least several decades. CO₂ emissions are directly related to energy consumption, which in turn is the biggest single cost factor in aviation. There is no unique alternative low carbon drop-in fuel available today that fits aviation requirements. The fuel industry needs to be challenged to accelerate the rate of development of commercial quantities of sustainable alternative aviation fuels, possibly through the introduction of economic incentives. To encourage this, the aviation industry needs to re-look at fuel
specifications and broaden the opportunities for alternative fuels. Ultra-low carbon energy sources should be developed, which may in turn require non-conventional vehicle solutions.

- **Mastering aviation climate impact** to allow low impact operations and technological decisions. The present global atmospheric models lack the capability to give adequate information with sufficient accuracy on the real atmospheric impacts of aviation. A deeper analysis of the mechanism of formation and dissipation of contrails and induced cirrus clouds and their contribution to the greenhouse effect is needed to evaluate the actual environmental impact of a given flight and, potentially, to optimise flight operations according to atmospheric conditions. Increasing the scientific knowledge of the physical processes involved in the interaction of aircraft and its atmospheric environment ensures that the best options for mitigation of air transport impact and for global environmental standards are established.

- **Incentives and regulations** are needed to create the right framework to promote environmentally friendly behaviour. This should be part of business-as-usual throughout all lifecycle phases from new aircraft design and development, over the whole operational period, up to aircraft end-of-life.
3.4 Dynamic management of target allocation, results survey and research priorities

To react fast and to get as much as possible from research activities, a new, joint and dynamic Aviation Community shared vision allows for dynamic governance of goals and roadmaps. Enhanced methods and processes allow all stakeholders to participate in the search for new solutions. Continuous performance evaluation is applied along the whole solution research process. Path-finding activities are used to identify new sources of improvement. In the long-term, continuous performance evaluation results are used to assess and where necessary reorient and redefine research activities.

As a first step and a starting point, an ambitious and appropriate split of key goals is established using a global approach between the key domains of air vehicle, propulsion system, operations and energy supply domain, along with the other lesser contributors. This takes mature evolutionary technologies and the emergence of disruptive technologies into account in the medium-term and underlines the need for disruptive technologies in the long-term. Full details of the ACARE initial proposals for emissions and noise targets are provided in Annex A.
3.5 Defining the air vehicles of the future

One of the principal aims of innovation of air vehicles is to improve fuel efficiency and environmental performance. Currently this is based on the single disciplines of engine technology, aerodynamics and flight physics as well as material and structural technology and needs to be sustained. But meeting the Flightpath 2050 goals requires dramatic changes in future air vehicle concepts for both the airframe and the propulsion system, the largest efficiency improvements being only achieved through a systemic approach. Taking this challenge into account calls for the parallel development of:

- A number of key technologies bringing benefit to both classical and new designs.
- New approaches to the overall design of the vehicle and of air transport operations.

**Key technologies**

Regarding key technologies, low drag and controllability techniques are applied as local spin-offs to current vehicles and generalised for next generation vehicles. These are based on smart structures combined with drag reduction techniques (natural and hybrid laminar flow morphing surfaces, flex wing concepts, engine integration, protection against gust loads and flying into vortex etc.). Conventional configurations are capable of supporting more efficient propulsion systems such as ultra-high by-pass ratio (UHBR) engines or contra-rotating open rotors. Similarly, low noise techniques for landing gear and high lift surfaces support the achievement of noise objectives.

**New materials** with low weight, high temperature capability and simpler maintenance properties are used for primary and secondary structures, cabin elements and engine structures. Optimum use is made of the properties of materials whether metallic, composite, ceramic, based on nano-technologies, or combinations of those. In addition to their inherent structural qualities, such as acoustic and thermal insulation, ice protection, etc., these new materials have the capability to support multiple functions. Ultimately self-repairing materials are widely applied. In particular, propulsion systems are based on light-weight, high damage-tolerance materials with very high specific performance at very high operating temperatures in an extreme and stressed environment. New materials are environmentally friendly in terms of manufacturing, re-usability and scarcity. The impact of nano-technologies on human health and safety is understood and mitigated where necessary. The overall design of the vehicle components and sub-components are fully compliant with regulations such as the Registration, Evaluation, Authorisation and restriction of Chemicals (REACH). Safe removal of parts and modules for re-use in the air transport industry is assured (including traceability) for full compliance to safety standards. Inventories are kept and the location mapped of hazardous materials and substances throughout the life cycle to enable recycling.

**Electrical technologies** are initially capable of managing on board vehicle energy demand in terms of safety, power density and full life cycle cost. In the longer-term, they are further developed to support the
hybridisation of the propulsion system and may, in some applications, replace combustion-based propulsion. Electrical power technologies are enabled through developments in energy storage and transformation, actuation and electrical motors, high power control and dynamic management (electronics), electrical conduction and heat treatment, for example for aircraft and engine energy harvesting. On-board systems enable optimisation of energy usage while minimising their mass and volume.

In the short and medium-term, propulsion system design exploits the residual potential of current and emerging designs through their evolution and optimisation. This includes, for example, turboprops; turbofans; geared turbofans; and open rotor architectures as well as helicopter turbines and auxiliary power units. Developments are supported by high-fidelity multidisciplinary virtual engine simulation capabilities. Specific capabilities are available at subsystem level, including low NOx and low particulate matter combustors as well as low noise and improved efficiency components. Improved thermal management systematically addresses and minimises all parasitic losses from powerplant systems. In the long and possibly the medium-term, propulsion system technologies support disruptive new vehicle configurations through seamless integration. These may include novel cycles and use of alternative energy sources (e.g. electricity) enabling new vehicle architectures such as hybrid, fully embedded and/or distributed systems with minimum energy use and noise footprint. Overall drag/thrust optimisation is supported by the integration of new propulsion concepts such as open rotor/ultra-high bypass ratio (UHBR) engines. Increased adaptability evolves across the flight and life cycle. Intelligent sensors, controls and actuation, as well as advanced health monitoring and proactive maintenance, reduce design margins needed for safe operation as well as performance deterioration during operation.

New aircraft systems that utilise new structure and material capabilities are also key technologies needed to develop novel propulsion and new vehicle configurations. System control and monitoring supports intelligent structures (adaptive forming wing, health monitoring, load control, etc.). Structural health monitoring is generalised to enable aircraft design to minimise the overall weight of the structure and satisfy all safety and operational requirements.

Flight operation systems permit flight in all-weather operations without requiring ground equipment for navigation. They also enable free flight to optimise trajectories in all traffic and weather conditions, including for example parallel landing, flight in wake vortex conditions, contrail generation avoidance, possibly formation flying, etc. These solutions are developed coherently with future air traffic management concepts. As highlighted in Challenge 1, this is enabled by seamless ground-air and air-air communications, accurate, reliable and resilient GNSS navigation capability, and specific on-board sensors for surveillance and situational awareness.

All these advances also call for enhanced methods, tools and research infrastructure (see Challenge 5) and advanced methods which are developed for design, testing and manufacturing processes. Computational science progresses towards the capability for multifunctional and multi-physical simulations. This enables rapid trade-offs for better technical integration, design using virtual reality while the manufacturing and the support phases are performed in an extended enterprise framework.

New approaches

Regarding new approaches to the overall design of the vehicle, dramatic changes in future air vehicle concepts for both the airframe and the propulsion system are needed to deliver the Flightpath 2050 long-term goals.
Novel structural concepts and design solutions for low-weight ensure optimum usage of the materials on-board the vehicles and enable multifunctional design approaches. These capabilities are interconnected and/or merged with the overall vehicle and system design tools. The single, distinct disciplines of engine technology, aerodynamics and flight physics as well as material and structural technology are integrated into a systemic approach to new air vehicle concepts, far from the classical design of separated tube, wings and engines and considerations of isolated aircraft systems. This delivers large efficiency improvements. The overall vehicle design is optimised for environmental performance and tailored to the integration of the vehicle in the ATS and its role in future air traffic management. A finely segmented approach to range, speed and payload without any loss of competitiveness is part of the vehicle design.

Unconventional configurations are developed, integrating the propulsion in the drag efficiency equation of the vehicle considering the airframe and propulsion as a single system or, e.g., in the VTOL sector where compound and tilt rotorcraft become technically and commercially viable. Optimised aerodynamic and structural integration with the airframe, including noise shielding, is implemented to reduce the requirement for trade-offs between the different environmental attributes, in particular noise and CO\textsubscript{2}. Integration takes the form of distributed propulsion, boundary layer ingestion (BLI) or other concepts realised through advanced engine and airframe technologies, such as smart structures and morphing surfaces. New design approaches, such as bio-mimicry, are also used to derive innovative concepts.

Future air vehicles are designed progressively for alternative energy supply for both on-board use and propulsion. Hybrid propulsion and electrical propulsion concepts are progressively available starting with lower power needs (general aviation, business jet, rotorcraft) and ultimately moving to high power needs (commercial aviation).

The optimisation of vehicles and of their environmental footprints is approached globally, over the entire lifecycle. Aircraft, including structures and systems, are designed in accordance with future environmental requirements concerning manufacturing, health and safety, recyclability, scarcity of materials. Design for reusability principles are applied at all stages of development based on the two main principles of minimising vehicle weight, including wiring weight, to deliver fuel/energy minimisation; and compliance with sustainability requirements. Design anticipates end-of-life and maximises the scope for recycling to leverage material scarcity, reduce energy consumption and waste.
3.6 Improving air operations and traffic management

In the short-term, greening of the operational environment capitalises on SESAR and Clean Sky results. It is achieved based on best practices and on sustainable growth, together with development standards for aircraft operations and ATS operations. Optimised processes, implemented jointly by ATM and operators, arise from new operational concepts based on multiple aircraft/fleet interactions in a large ATS approach, with the air travel segment as part of a multimodal door-to-door journey. Better understanding and assessment of environmental and socio-economic impacts enables tactical and real-time adjustment of operating practices to minimise environmental impact. Monitoring of fleet operations provides visibility to customers of options and associated impacts giving them the ability to actively participate in greening their travel itineraries (described in Challenge 1).

Improving air operations and traffic management delivers significant environmental benefits. Fuel usage (and hence CO₂ emissions) and perceived noise are decreased by the individual optimised operation of each aircraft. Each flight phase, as well as global flights, are optimised for environmental efficiency in the new ATM context developed by SESAR. 4D-trajectory management is generalised. Weather conditions and their impacts are accounted for in flight planning and in real-time, including the influence of winds, adverse weather conditions and contrail formation.

In the medium-term, trajectories are optimised and fuel burn minimised by the deployment of new operational concepts such as free routing and free flight. This is enabled by flexible flight management systems, accurate satellite navigation systems and new atmospheric sensors. In addition, aircraft networking allows, among others, to share situational awareness and enables self-spacing for optimal runway capacity. In the long-term, more sophisticated features, such as formation flight, are implemented.

Additional gains are also delivered by the identification and assessment of environmental benefits at aggregated multiple trip level, leading to flexible/adaptive schedules by operators. Air trip optimisation can then be extended to the global transport network, including ground transportation.
3.7 Improving the airport environment

The local air quality impact of aircraft is mainly determined by engine combustors. Trade-offs between different pollutants (NO\textsubscript{x}, CO\textsubscript{2}, unburned hydrocarbons, particulates) and low fuel burn have to be made. A better scientific understanding of the effect on health and the control of particulate matter informs this trade-off. Emissions-reducing measures that can directly be influenced by the airport focus on aircraft ground operations, ground handling and terminal operations to reduce both the local air quality impact and the carbon footprint. The correct assessment of air quality impact at and around airports is based on precise and efficient measurement and prediction of air vehicle exhaust emissions as well as accurate atmospheric transport modelling.

Noise nuisance constraints to airport expansion are overcome. The increased role of the rotorcraft sector, with improved conventional helicopters and through the development of advanced vehicle configurations like tilt-rotors and compound architectures, leads to an increased presence of heliports and vertiports in the densely and sparsely populated areas alike. In addition, en-route noise from future aircraft architectures or novel vehicles flying low altitude routes is managed effectively.

Mitigation of the airport’s environmental impact is supported by the availability of a fully integrated European environmental impacts tool suite. Supporting this tool suite, accurate knowledge of engine exhaust emissions is provided both by emissions measurement systems and by prediction relying on atmospheric transport modelling.

The development of the airport is sustainable in a way that contributes to an improvement of the health environment within its boundaries and surrounding communities. To achieve this, fixed power, green land transport vehicles are fuelled with low carbon energy. The utilisation of environmentally friendly chemicals (e.g. for aircraft de-icing) and sustainable approaches to energy and water use are generalised. Maintenance, decommissioning and disposal operations integrate sustainability criteria. Access by land transport is performed with ‘green’ infrastructures and vehicles.

The approach for reducing the airport’s environmental impact is global. In the policy arena, the principle of ICAO’s balanced approach for reducing noise annoyance is maintained. This consists of noise reduction at source, land-use planning and management, operational procedures for noise abatement and aircraft operating restrictions. Supplementary to this, a multi-stakeholder approach for reducing emissions is applied within the boundaries of the airport. This approach is managed in collaboration with communities around the airport.

In terms of operational and infrastructure measures, more energy-efficient airport processes are applied including a greater use of renewable energy to achieve a low carbon footprint. This includes the whole energy chain of production, distribution, conversion, supply, storage and
consumption. The total emissions of aviation ground infrastructure are minimised based on a multi-disciplinary approach for the optimisation of airside and landside layout. Aircraft noise and emissions are mitigated through operational and infrastructure design and optimisation supported by improved operational processes, including noise abatement procedures and ground handling. Emission free taxiing is an integral part of the airport operation. In addition, airport surface access, whether it is by individual or public transport, surface or underground, is improved and its environmental footprint reduced.

Land-use planning and development around airports is managed on a long-term basis, recognising the benefits and penalties of such proximity and is used to integrate the airport into its neighbourhood. This is based on full partnership between transport operators and local authorities. There is a full understanding of the effects (nuisance, annoyance, sleep disturbance, health effects, etc.) of emissions, noise and other aviation impacts.

Airports are developed into SMART Airport cities. The SMART Airport city applies a comprehensive environmental management system underpinned by measurements and a monitoring system to address, inter alia, water, waste, biodiversity, noise and emissions. This approach covers not only real estate (including, for example, the terminals, other buildings, road systems, etc.) but also the infrastructure for all airport processes (e.g. runway lights, baggage system, security, ground handling) and airport activities (office buildings, commercial areas, parking areas, etc.). It encompasses the local generation and efficient management of energy (e.g. solar, biomass) and the improvement of the energy performance of the buildings. The SMART Airport city is developed with the engagement of the stakeholders (e.g. airliners, passengers, local and national government, employees, authorities) and in line with corporate social responsibility.

Neighbours have a positive image of aviation. This is achieved by minimising the real and perceived effects of noise and emissions of the transportation infrastructure (aviation and other modes of transport) as well as executing a positive and transparent communication strategy to and with neighbours. Proper access is guaranteed to the airport through good relations with neighbours.
3.8 Providing the necessary quantity of affordable alternative energy sources

Alternative fuels can be produced from fossil sources such as coal, natural gas, biomass (e.g. oil plants), animal fat, lignocellulose or eventually from industrial wastes (exhaust gas). However, only fuels derived from biomass, renewable sources or from waste allow a reduction of greenhouse gas emission. These fuels can be considered as sustainable provided they meet applicable sustainability standards. As a starting point, in June 2011 the European Commission initiated the Biofuel Flightpath initiative aiming at producing two million tonnes of biofuel per year by 2020.

Since breakthrough technological solutions with zero emissions will not be available in the short-term, sustainable alternative fuels are supported as a very promising means of reducing the carbon footprint of aviation. Europe sets ambitious targets in this respect. In the medium-term, aviation remains dependent economically and technically on the availability of liquid hydrocarbon fuel, albeit with sustainability as a key requirement. Aviation increases its use of sustainable alternative fuels to a minimum of 25% in the medium-term, thus contributing to carbon neutral growth of air transport from 2020 onwards. In the long-term aviation uses at minimum 40% sustainable alternative fuels in Europe, as stated in the EU’s 2010 Transport White Paper. To meet fully the Air Transport Action Group (ATAG) global target of halving aviation’s CO₂ emissions in 2050 compared to 2005, a still higher proportion of alternative fuels is necessary.

A harmonised energy policy fosters the development and deployment of sustainable alternative fuels for aviation, in particular biofuels. It encourages and de-risks investments in production and helps bridge the current price gap with fossil kerosene so that sustainable fuels are competitive price-wise. The policy creates a level-playing field for sustainable aviation fuels with land-transport fuels and ensures their competitiveness. Incentives are applied to accelerate large scale commercial production of alternative fuels suitable and affordable for aviation, either through active energy industry involvement or new entrants. This is supported by the inclusion of aviation in bioenergy development plans and the associated agriculture roadmap. Synergies with the land transport biofuel sector are developed and the issue of competition between sectors for the same feedstock is solved. Stable and globally recognised sustainability standards are defined for the certification of alternative fuels for aviation to overcome uncertainties and methodological issues. The standards ensure usability of the same sustainable fuels throughout a worldwide route network enabling biofuels to deliver their potential for greenhouse gas emission reduction on a life cycle basis.

The energy sector undertakes research and development on innovative production processes to produce economically competitive and sustainable drop-in fuels. Research also increases the knowledge of acceptance conditions at engine and
aircraft level and facilitates approval of new drop-in fuels to enlarge the aviation fuel family. The involvement of the European stakeholders with an interest in fuel approval is assured through the establishment of a European network of competences.

In the longer-term, the aircraft/fuel tandem is optimised for better environmental and economic performance, taking into account possible impacts on infrastructure.

Longer-term R&D develops radical new fuel solutions, e.g. with low carbon content or more advanced solutions. In parallel, research on sustainability issues (life cycle assessment, sustainable agriculture, etc.) is continued.
3.9 Mastering aviation climate impact

Models and experimental techniques are developed in order to obtain a full scientific understanding of the aircraft-atmosphere interaction, and to implement the measurement capability necessary to inform decision-making based on that understanding. This allows aircraft operators and manufacturers to choose the best options for mitigating air transport’s environmental impact, based on detailed knowledge and understanding. The establishment of relevant global environmental standards is possible since a high level of scientific understanding has been obtained.

A full knowledge and understanding of aircraft emissions is acquired. This is based on accepted measurement techniques for full characterisation of exhaust emissions as well as full engine emissions characterisation and quantification (including particulate matter) on the ground, in altitude test cells, and in flight. In support of this, computational fluid dynamics models have the ability to predict 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) allows measurement of pollutant concentrations in the atmosphere at the global scale, in a particular flight corridor or behind specific flights. In addition, the capability is developed to monitor changes in the extent and optical properties of clouds arising from aviation activity both at individual flight and global levels.

The monitoring of detailed atmospheric conditions along a proposed flight path supports decision-making.

The level of scientific understanding of aviation’s non-CO$_2$ impacts is increased to underpin a well-balanced approach for reducing aviation’s total climate impact, taking CO$_2$ and non-CO$_2$ impacts into account. Scientific understanding of the physical processes of the interaction between aircraft and the atmospheric environment has been significantly improved. Scientific tools are developed and adapted to analyse the current and future impact of the aviation industry. Atmosphere and climate models at different geographic and time scales are adapted or developed, as well as specific measurement techniques for model validation. This research moves the aviation sector towards a single framework for expressing, quantifying and managing long-term impacts alongside shorter term impacts, through the use of appropriate and representative metrics.

Numerical simulations and physical models are developed to describe accurately the processes that affect aircraft engine emissions in the atmosphere. The whole range of aviation induced effects on different time and space scales is correctly accounted for. The role of NO$_x$, contrails and induced cirrus clouds is modelled with high accuracy. Models take into account atmospheric feedback due to the aviation emission on different time and geographic scales. Tools and algorithms are available to exchange
data easily between models operating on different scales as well as to provide the flexibility to import data from new sources when they become available. Eventually the new tools allow each individual flight’s contribution to climate change to be quantified (using an appropriate metric).

Enhanced **environmental impact monitoring infrastructure and processes** are in place. The monitoring infrastructure includes specific instruments arising from particular aviation needs. This includes sensors carried on air vehicles themselves as well as information on global atmospheric conditions collected by more general earth observation and prediction systems (both global and local). The system is able to provide precise environmental information to the advanced air traffic management system. In addition to traditional flight optimisation, such as minimum flight time or minimum direct operating costs, this allows optimisation for minimum climate change, or a combination of minimum climate change and minimum direct operating costs. Eventually, airframes are optimised for flight trajectories with minimal climate impact.

Mitigation of the airport’s environmental impact is supported by the availability of a fully integrated **European environmental impacts tool suite**. Supporting this tool suite, **accurate knowledge of engine exhaust emissions** is provided both by measurement using an emissions measurement system and by prediction based on atmospheric transport modelling.

As it develops, the scientific understanding outlined above is communicated to relevant policymakers and regulators. This enables policy and regulations to be founded on sound scientific principles and understanding.
3.10 Incentives and regulations

Previously, different aspects of the environmental impact of aviation were regulated at local, national, supra-national and international levels. Legislation applied to new products (i.e. environmental certification standards), to local or regional fleet operation (e.g. noise dependent landing fees) or to a global fleet operation (e.g. ICAO noise abatement procedures).

To achieve the Flightpath 2050 environmental goals, the EU legislative, regulatory and fiscal/financial frameworks are streamlined to accelerate development and deployment of technologies that reduce environmental impact. Assessing the economic impact of different combinations of controls, incentives and instruments is crucial.

Economic measures are in place at global level to complement technical achievements and incentivise the use of the greenest technologies. **Regulations and incentives** are applied to encourage optimised operations. They are based on the appropriate standards and move from static schemes, e.g. based on type certificates, towards differentiation according to actual performance. **Recycling of aircraft in Europe is incentivised.**

Incentives to accelerate innovation in environment are applied and address metrics and targets for fleet environmental performance, the reduction of development and certification costs and acceleration of fleet replacement to foster greener performance. Appropriate **funding instruments promote the introduction of greener technologies**, for example, tax credits reward innovation. Public procurement policies support greener products.

Environmental innovations in regulations and businesses are built on **effective cross-fertilisation** and knowledge-sharing with other sectors.
3.11 Timeline

2020

**Air vehicle**
- Optimised conventional aircraft and engines using best fuel efficiency and noise control technologies
- Multidisciplinary/multiphysical methods and simulation

**Air transport system**
- Multi-criteria flight optimisation at aircraft level
- Low emission taxiing
- Reduced & renewable energy use in airports
- Policy instruments facilitating innovative investments

**Sustainable energies**
- Initial industrial production of sustainable alternative fuel
- Faster approval process for new drop-in fuels
- First global harmonisation of sustainability standard
The following figure provides an illustration of the high-level evolution of the capabilities needed to meet the goals of Challenge 3. SRIA Volume 2 provides more detailed information on evolution of the enablers, capabilities and technologies needed to meet this Challenge as well as the metrics used for monitoring progress.

- Ultimate conventional engines
- First application of configurations with hybrid propulsion
- Multifunctional materials
- Fully electrical on-board energy
- End-of-life policy & technology
- Full-time connected aircraft

- New ATM concepts
- Multiple trip aggregated optimisation with adaptive scheduling
- Emission free taxiing
- Improved airport access

- Strong ramp-up in biomass and biofuel production
- Evolution of fuel specification for optimised fuel-aircraft tandem

- Radically new A/C concepts
- New thermal cycle & alternative energy propulsion
- Nano-engineered materials, easily recyclable biomaterials

- Full autonomy aircraft
- ATM supports mixed fleet (piloted and pilotless aircraft)

- Radical new low carbon solutions
Challenge 4

Ensuring safety and security
Progress in aviation safety since the 1960s is impressive. Lessons have been learnt from the accidents and risk-bearing incidents of the past. Effective measures have been implemented to reduce the probability of similar events today and in the future. However, the safety goals for 2050 are very ambitious. It is unlikely that the typical root causes to be cured are known with any certainty. While some of these may be considered as known unknowns, others, the unknown unknowns, will emerge and become more prominent as technologies advance or as disruptive events such as extreme atmospheric conditions tend to become more frequent.

To ensure future generations enjoy the mobility options offered through safe and secure air travel, methodologies need to evolve to identify the emergence of future risks and to accommodate these through improved design, manufacturing and certification processes, taking into account the global nature of aviation. This extends beyond commercial operations, to domains where the use (and abuse) of aircraft and the emergence of new aerial applications may change radically and potentially constrain airspace, creating new hazards and/or significantly increasing traffic density and complexity.

Safety and human performance are inextricably linked. The importance of integrating human performance into the system to increase its resilience and tolerance to error is vital. The human dimension needs significant attention to ensure that the future work place, procedures and supporting systems are designed for the individual as opposed to the individual adapting to the work place. Vigilance is maintained and systems are able to monitor, detect and correct abnormal behaviours.

Aviation security is a relatively more recent domain compared to aviation safety. Today from a customer perspective it appears that security is airport centric and is reactive to events and threats, both perceived and real. However, security processes go far beyond what the customer perceives:

- **Pre-flight security** where measures are implemented to prevent weapons, explosives or any other dangerous devices, articles or substances, including those entering into the supply chain (fake parts) from being introduced on board an aircraft. This covers access controls, screening of passengers and staff and security controls of cargo, mail, airport and in-flight supplies. It also encompasses the protection of the air vehicles while on the ground against physical, explosive or cyber-threats. Other measures comprise screening of relevant flight information and personnel, education, awareness, training and security exercises.

- **In-flight security** ensures aircraft can fly securely and have the capacity to neutralise threats which could infiltrate the vehicle, its equipment or software. This includes, for example, on-board security, the cyber-security of the aircraft’s systems and the security of the vehicle as it travels through airspace. It also encompasses incident management.

- **Post-flight security** supports incident reporting and analysis, forensic/investigations and the identification of corrective actions.
• **Air navigation and traffic control security** concerns the communications and other safety critical electronic systems and infrastructure that monitor and controls the safe passage through airspace against physical and cyber-threats. This also includes support to other aviation security areas, national security and defence authorities, customs and law enforcement.

In-flight and cyber-security issues are becoming an increasing concern. The introduction of more complex communications and electronic systems on-board new aircraft increases their potential exposure to hackers. In line with the objectives of Flightpath 2050, the short-term priority is to improve the efficiency of aviation security measures imposed on passengers, staff and cargo in order to better mitigate the existing threat while facilitating travel and trade. Security measures also need to anticipate future and evolving threats.
4.2 Targeted achievements for 2050

Aviation is a system-of-systems with human, social and organisational processes, operating technologies that are partially integrated and partially automated. Transport is even more of a system-of-systems. Integration of aviation with other system elements of other transportation modes realises the goal of an integrated transport system with seamless security across modes. System science is expanded to encompass all elements. The piecemeal, fragmented nature of research, particularly on the human/organisational aspects is addressed and metrics and capabilities developed to measure the effectiveness of the research. The interfaces between the different transport modes are sufficiently understood from both the physical connectivity perspective and the customer service perspective. Operational research, fundamental to effective progress in the fields of transport safety and security, is expanded in scope, is increasingly effective and is on a par with technology development.

Risk is reduced in relation to both safety and security. The measurement of risk moves from the use of expert judgment supported by crude outcome statistics, to an evidence-based, empirical capability relying on system performance, linking inputs and outputs of the system, and dealing with complex system interactions. This enables all relevant aspects of system effectiveness to be measured. The relation between systems and culture is understood sufficiently in the context of implementation and change. This understanding improves the success rate of change programmes and major technology implementation projects. The development of much clearer mechanisms to measure risk and manage change efficiently – at the level of the operational system - enables smart regulation that has effective oversight of what that operational system is doing.

Certification practices are adapted to cope with the integrative role of new technologies and their potential to transform relations across a system-of-systems. New capabilities to design-for-operations facilitate and contribute to more efficient time-to-market. There are new standards and procedures for system and procedure development. Certification, operator approval and licensing processes are joined-up in terms of identifying and managing system risk. Safety and security in the design phase are linked transparently to the operational phase of the system lifecycle.

The increasing use of information technologies facilitates the identification and mitigation of emergent risks. The associated safety and security challenges arising from higher levels of integration and interdependence are overcome.

Trust in technology is bound up in qualities such as reliability and usability. Trust in people relates to the quality of social relations. The increasing use of information systems blurs this distinction and raises the issue of inappropriate trust in new ways, precisely because of the power of simulation by information systems. Issues of governance and trust are more acute with the increasing use in core functions of commercial-off-the-shelf (COTS) hardware and software manufactured in different regions, and the increasing diversification of supply chains for information technologies.
that link different parts of the ATS and their host organisations. Increasing integration intensifies the collaboration that is necessary between commercially competing organisations. This brings increasing focus on trust in management, governance and regulatory systems. Trust in the system and confidence in its governance mechanisms are key design goals. The critical risk issues of authenticity and integrity of data are also addressed. Information systems are used to create high reliability through defence-in-depth.

Benefits are derived from synergies between civil and military technologies. This is based on the evolution towards enhanced interoperability and convergence of civil and military infrastructure, which sustains mixed mode operations and common performance targets. This development contributes to overall efficiency and safety objectives by enabling the seamless integration of dissimilar airspace users in a common Single European Sky context, minimising capability mismatches.

Safety and security systems are integrated with business management systems, ensuring that safety and security are built-in by design and are efficient, effective and dynamic enough to adapt and respond to a fast changing and evolving threat and risk scenario. They are able to provide the flexibility to reconcile the long-term evolution, which to a degree appears predictable with developments of a non-predictable nature. The ever-present attacker-and-defender conflict is given urgent focused and on-going attention.

Research capabilities have identified, understood and overcome emergent characteristics and behaviours of complex system operations, demonstrating safe and secure operations within very large, fully integrated and interdependent socio-technical systems. Technology readiness levels give way to integrated system readiness levels.

**FLIGHTPATH 2050 GOALS FOR CHALLENGE 4**

1. Overall, the European ATS has less than one accident per ten million commercial aircraft flights. For specific operations, such as search and rescue, the aim is to reduce the number of accidents by 80% compared to 2000 taking into account increasing traffic.
2. Weather and other hazards from the environment are precisely evaluated and risks are properly mitigated.
3. The European ATS operates seamlessly through interoperable and networked systems allowing manned and unmanned air vehicles to safely operate in the same airspace.
4. Efficient boarding and security measures allow seamless security for global travel, with minimum passenger and cargo impact. Passengers and cargo pass through security controls without intrusion and unnecessary intervention or disruption.
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 ATS has a fully secured global high bandwidth data network, hardened and resilient by design to cyber-attacks.
4.3 The enablers to reach the goals of Flightpath 2050 for Challenge 4

Enablers describe what is needed to achieve the goals. Capabilities describe how the goal can be achieved. The general enablers needed to realise the goals associated with Challenge 4 are as follows.

• Societal expectations: identifies the enablers and capabilities that are needed for aviation to meet the needs of society in terms of safety and security, both from the perspective of the customer of aviation services and that of the citizen subjected to the impact of aviation.

• Air vehicle operations and traffic management: addresses the enablers and capabilities that are needed to provide safe and secure operations, managing the diversity of air vehicles and aerial applications while transiting airspace and on the ground.

• Design, manufacturing and certification: focuses on new approaches to the conception, building and certification and approvals of system components aiming to ensure that safety and security requirements are built in from the outset and reducing time-to-market of new products and services. These enablers take into account the growing influence of software as well as the high levels of automation and integration in the ATS of the future.

• Human factors: addresses the research and innovation needs to support and optimise the human roles across the ATS. These enablers consider the ever-increasing volume information available as well as the shifting demarcation of authority and responsibility between the human and the machine.
By their nature, aviation safety and security are perceived and approached differently by the consumer and the citizen. While safety measures are usually applied at organisational levels and are largely transparent to the travelling individual, in most cases security measures are the source of inconvenience to the consumer of aviation services. Consequently, while safety is usually taken for granted by the general public and is only questioned whenever a serious incident occurs, security is regularly imposed upon the consumer and provides a major source of annoyance.

In order to really produce high levels of security for the decades to come, security systems, processes and philosophies need to be motivated by effectiveness and efficiency as well as contribution to overall security targets. The reaction to incidents and security breaches is objective and measured. Public acceptance of security measures is commensurate with the perception of threat and thus with the perceived level of personal insecurity. Travellers and customers of the ATS are aware of the impact of security measures to their travel schedule, which helps resolve some of the frustration encountered when confronted with measures that frequently appear excessive and unjustified. This does not imply that the security mechanisms themselves are predictable, but that their overall impact on the individual traveller or customer is quantifiable with the aim to minimise and considerably reduce the inconvenience.

The emergence of the fully digital society has raised many new security issues. These included privacy matters, ethics, misrepresentation as well as personal and public security from cyber-crimes. New terrorist targets and business models have emerged, forcing authorities to re-evaluate the threat assessments in a flexible manner. All members of society have very high awareness of digital security from an early age, starting with school education.

4.4.1 SYSTEM-WIDE SAFETY MANAGEMENT

A system-wide Safety Management System is identified and implemented to operate throughout the whole chain of air transport activities in the context of the total transport system. Safety management systems are integrated with security management and enterprise management systems.

System-wide safety management is based on a comprehensive understanding of the safety-related influence factors on the overall ATS and its connections with other transport nodes. An overall safety framework is created, which ensures equity in access to airspace by all air vehicles. The Safety Management System is overseen by a multi-modal transport safety governance framework where competences, regulatory bodies, accountabilities and oversight mechanisms have been identified and implemented. Performance-based safety regulations, procedures and risk-based oversight and control mechanisms are globally standardised, straightforward and comprehensive.

The ATS has demonstrable safety resilience to react, respond to, and recover from safety threats. It is based on an understanding of human and organisational performance.
and on how to infuse a positive safety culture at all levels.

Tools, metrics and methodologies are available to assess and manage proactively current and emerging risks. Tools and models have been developed which enable the pre-emptive identification, probability and impact of the potential hazards resulting from climate change and other external hazards.

Safety performance indicators are systemically linked to safety outcomes, allowing measurement of system safety performance. There are efficient automated look-up procedures, data exchange and data fusion mechanisms across heterogeneous data sources for aviation safety related issues. Data integration across the ATS links system antecedents to safety outcomes enabling quantitative risk assessments and measurement of risk reduction. Credible measurement of progress towards 2050 targets is possible.

The capability exists to assess and mitigate risk in an intermodal door-to-door transport environment.

4.4.2 SYSTEM-WIDE SECURITY MANAGEMENT

A Security Management System is developed to operate throughout the whole chain of air transport activities as a component of the total transport system and in accordance with societal expectations and civil rights. Security Management Systems are integrated with safety management and enterprise management systems and security culture is infused at all levels across the ATS.

Similar to the Safety Management System, the Security Management System is based on a comprehensive understanding of the security-related influence factors and vulnerabilities within the overall ATS and its interfaces and integration with other transport modes. It is overseen by a
multimodal transport security governance framework where competences, regulatory bodies, accountabilities and oversight mechanisms are identified. This framework includes a crisis management capacity and is based on globally standardised agile security regulations and procedures with an adequate oversight and control mechanism. It provides clarification of the implication on liability, insurance, etc. of aviation security risk and oversees consistent application across the EU. Finally, it ensures that security measures are compliant with European rights of citizens, cultural and religious demands and constraints.

The Security Management System is based on the identification and implementation of a risk-based approach for aviation and transport security. It is supported by tools, metrics and methodologies that are developed and available to assess and proactively manage security risk. Sophisticated models of security risk build on historic data, but anticipate new forms of threat. In addition, there are efficient automated look-up procedures, data exchange and data fusion mechanisms across heterogeneous data sources and an improved forensic capability for resolving physical and cyber-security incidents. Appropriate performance concepts for security are developed, which are commensurate with the nature of the potential threat.

There exists a good understanding and effective mitigation of the vulnerabilities of information systems to cyber-attack, with respect to their representation of people, in providing networks and in the provision of task support. The system is capable of anticipating and adapting to new threats. There is also enhanced capability to reduce the ability of people and organisations to obtain harmful devices and provisions are made to reduce their effectiveness.

Security performance indicators are systemically linked to security outcomes, allowing measurement of system performance. Credible measurement of progress towards 2050 targets is possible.

4.4.3 AN INTELLIGENCE-BASED APPROACH

Innovative methods, processes and services are to be developed which fully exploit available information. This allows the proactive identification and prevention of current and future security threats to the total ATS. Intelligence is embedded into the threat assessment process and is based on all-source information supported by research into the detection of emerging risks. This Risk Watch is supported by the ability to access and perform background information analysis on personnel employed in the ATS and people using the ATS, as well as the establishment of services and processes to distribute necessary and relevant information at the right time, in the right place, to the right people.

Controls are applied to ensure the compliant handling of privacy and civil rights legal issues addressing the ownership of the data, access rights and longevity of data.

The intelligence based approach enables innovative measures to facilitate transit of passengers, luggage and goods through the security and immigration, customs and embarkation processes at air transport connection nodes.
4.5 Air vehicle operations and traffic management

The airspace in the year 2050 has evolved considerably. Apart from the continuous growth of the number of aircraft and an increased demand for air travel, there are new forms of flying vehicles and aerial applications. These are integrated seamlessly into the air traffic scheme. New technologies and applications introduce new safety challenges. In addition, airspace is ever more crowded. Consequently, air traffic management concepts evolve along with the growing demand to achieve safety and security goals. Instead of a number of mostly isolated aircraft moving through airspace, there is a multitude of different co-operative and uncooperative elements in the all-encompassing data space incorporating aircraft movements, trajectories, live performance, vehicle status information as well as copious other kinds of data. This leads to – and requires - increased situational awareness and innovative mechanisms to optimise dynamically separate each air vehicle with new levels of collaboration and trust between the actors. Safety throughout the operation is further improved through the use of self-healing systems, devices and materials able to detect abnormal behaviour and reconfigure themselves.

While the evolution of the vehicles and their supporting systems changes the manner in which transport services are provided to the customer, a new generation of air transport interface nodes facilitates safe and secure transit for passengers and goods, across transport modes seamlessly, with minimum inconvenience, queuing and processing.

4.5.1 SAFETY RADAR

The safety radar comprises innovative methods, processes and services to ensure the identification and detection of safety hazards. It is enabled by the proactive identification of atmospheric and other external hazards. Models are developed that enable the identification of hazard probability, impact and mitigation. The safety radar is also underpinned by behaviour analysis of passengers, staff and personnel to identify in real-time abnormal behaviour, mobility patterns, etc. to identify hazards to safety. Similar to the personal level, this is extended to behaviour analysis of airspace and airport use.

4.5.2 SECURITY RADAR

The security radar is analogous to the safety radar and comprises innovative methods, processes and services which ensure the identification and detection of security threats. It is based on the reliable detection of abnormal cyber-activity/behaviour that poses a threat to the integrity of the air transport operation. It makes optimum use of efficient and fast minimum impact sensor technologies to detect dangerous goods in the transport chain and monitoring systems to detect abnormal movement of cargo and baggage.

The security radar is underpinned by behaviour analysis for passengers, staff and personnel (e.g. vigilance, abnormal behaviours, mobility patterns etc.) to
identify security hazards supported by non-invasive and non-intrusive security technologies and procedures for passengers.

**4.5.3 OPERATIONAL MISSION MANAGEMENT SYSTEMS AND PROCEDURES**

Operational mission management systems and procedures are concerned with protection and responses that facilitate hazard risk management through use of the appropriate tools, including atmospheric models. They enable the optimisation of trajectories to ensure hazard and collision avoidance throughout all flight phases and with the earth’s surface. They also enable the safe access and integration of non-commercial flights, personal air vehicles and UAV within airspace and airports and ensure that commercial space operations are merged safely with traditional atmospheric flight operations and airspace structures. Innovative usage concepts are used to maximise the utilisation of scarce resources such as airspace, runways and parking.

To support accurate mission planning, a complexity assessment modelling capability is available together with models to identify and predict meteorological and other environmental hazards affecting flights.

In order to ensure hazard avoidance while in-flight and on the ground, systems and new traffic services are coupled with on-board sensor technology that monitor atmospheric conditions, airspace environment, traffic proximity and flight data. This is supported by intelligent automation systems, with optimal man-machine integration and interaction, as well as secure, redundant CNS systems that are robust to failures of individual components and ensure global coverage.

Organisational structures are globally networked to support crisis management with intelligent decision-making support under high work load and stress. In the case of accident or incident, integrated search and rescue capabilities are available with rapid and appropriate intervention whilst in the security domain there is unequivocal and positive identification, tracking and monitoring, and neutralisation of all threatening flight objects. This relies on commensurate security intervention methods, tools, technologies and processes to neutralise active threat.

**4.5.4 SYSTEM BEHAVIOUR MONITORING AND SELF-HEALING**

This concept is concerned with systems that enable the proactive detection of degraded and abnormal situations and support optimised self-healing. Automatic reconfiguration/re-routing in response to safety or security vulnerabilities is enabled by the continuous usage and health monitoring of airports and airspace. In addition, global surveillance and vehicle monitoring capabilities ensure the tracking and location of air vehicles throughout the mission and initiate search and rescue in case of serious incidents. Innovative machine health monitoring systems, maintenance processes and tools ensure that critical systems and technologies remain operationally sound.
4.6 Design, manufacturing and certification

A fresh perspective shapes the way that the components of the ATS are conceived, built and certified. Addressing the ambitious challenges of Flightpath 2050, safety and security are high amongst the primary concerns of aircraft and aviation systems design, along with the more classical concerns such as mission performance and cost effectiveness. New approaches are developed that allow these concerns to be an integral part of systems design even from the very first design phases. In addition, the effects of new forms of (software) system design and code generation and the impact upon safety and security are studied. The increasing use of commercial-off-the-shelf chips and software raises new issues. The potential to introduce a back-door into future systems is a new threat to the integrity of such systems. New materials such as the ones based on nano-technologies and new manufacturing techniques necessitate thorough investigation regarding their consequences for safety and security.

New certification and approvals processes are in place. The growing influence of software on all elements of aviation results in an adapted certification process capable of handling high levels of automation in system engineering and utilising advanced verification methods, with the ultimate goal of ensuring both highest safety and security levels as well as reduced time-to-market, even for the most sophisticated and highly integrated systems.

4.6.1 Diagnostic Analysis

Diagnostic analysis uses tools, methodologies and processes to automate the capture and analysis of aviation accidents, incidents and occurrences. It further improves the efficient identification of trends and emergent hazards, to mitigate the risks to aviation safety and security. Diagnostic analysis supports technology, operational and regulatory impact assessment, accounting for new requirements and designs and their effect on human performance. Success is based on reliable safety data (incident reports, flight data etc.) that is widely available to stakeholders due to improved capture technologies, processes and safety culture. This not only covers commercial air transport but also general aviation and non-transport operations enabled by new technology and cultural evolution. Similarly reliable security data (incident reports, operational data etc.) is widely available to stakeholders due to improved capture technologies, processes and security culture. New sensor technology is in place allowing capture of key data from safety and security events.

Heterogeneous data from all sources are brought together and stored in secure, global databases, established, managed and accessible for data retrieval and analysis using appropriate methods for analysis which allow all types of safety and security issues to be quickly identified and understood.
4.6.2 EFFICIENT AND EFFECTIVE STANDARDISATION AND CERTIFICATION

Innovative approaches to the standardisation, certification and approval processes are to be developed where advanced methodologies, including simulation tools, are applied to compliance demonstration of safety/security requirements at component, product, system and system of systems level. This encompasses human, social and technical aspects, leading to efficiency and shorter time to market of new products, services and operations. This also concerns improved methodologies for standardised approval and licensing.

The standardisation and certification processes are built on a common roadmap developed between EU and other aviation leaders, resulting in international standards for security technologies and processes. These are supported by methods and tools that facilitate the verification required for the global standardisation, certification and approvals processes, which are all joined up at the ATS level.

Efficient and effective standardisation and certification relies on harmonised approaches, methods and tools between operational safety and security as well as a common certification approach for security systems.

There are common systems and processes for certification/approvals. This allows, where the virtual environment is the accepted means of compliance, to enhance the efficiency by, for example, the incremental certification of applications, taking into account increasing levels of system complexity. Flexible systems and processes are in place to allow robust and rapid update of evolution to certification requirements for emerging technology or other requirements (e.g. open rotor, compound and tilt rotorcraft, UAVs, single pilot, open source software/hardware, environmental threats).

4.6.3 RESILIENCE

Resilience covers the methodologies and tools, products and services which ensure the ATS is robust by design and operation to current and predicted safety and security threat and hazard evolutions. Cross-fertilisation of ideas, concepts and best practice are achieved through the construction of coordination forums encompassing various interested parties, including other transport means, when designing the system.

Resilience includes IT security concepts resilient against cyber-attacks and applied throughout the global aviation system, based on a novel design philosophy leading to an inherently safe and secure ground infrastructure and airspace (use). In particular, communications and other critical electronic systems and infrastructure that link the aircraft and the ground are resilient to failure and cyber-threats.
Resilience is based on current and emergent environmental and security hazards being characterised and understood, and accurately mitigated by design. Resilience is increased by applying systematic methods to feedback the results of safety and security analysis into the design process as well as to feedback operational experience into the design and manufacturing process.

New materials, new manufacturing techniques, design approaches and new vehicles are developed to improve the safety and security of the design (e.g. self-healing of material, privacy by design, new fuels, new airports, electric propulsion, improved sensors, protection devices, preventive measures towards counterfeit parts). They are also applied to improve the survivability (active and passive measures) of transported people (e.g. through new cabin and airframe designs). Airworthy aircraft are constantly in service with minimum deferred defects. The aircraft health management system supports human and operational processes and enables overnight equalised maintenance programmes.

A methodology and toolset for advanced systems engineering is available that fully incorporates the human and social aspects together with technologies and information systems in order to address both the necessary complexity of designs, the need to manage a large number of stakeholder requirements and to ensure system goals. This will allow safety and security requirements to be fully integrated into the design from the earliest stages. In addition, complex software development and certification is optimised taking into account safety, security, speed and effectiveness (e.g. auto code generation, self-healing software, monitoring software).

The human contribution to systems resilience is based on an improved understanding of human factors and psycho-social issues for application to design and manufacturing as well as the availability of a suitably qualified, trained and adaptable work force and a framework that ensures the continued support to both legacy and emerging technologies.
Human factors is the discipline of understanding the interactions among humans and other elements of a system to optimise human well-being and overall safe system performance. Human factors comprise cognitive and physical characteristics of individuals as well as their social behaviour.

The challenges for human factors centre around moving beyond a largely cognitive focus (centred on the individual or crew), to a systemic focus in which people’s behaviours contribute to process outcomes, be it as individuals or teams within formal organisations, informal organisational or social frameworks. This encompasses the co-ordinating role of people in complex systems-of-systems and fully addresses an integrated management concept. The focus is to make human factors more responsible for measurable improvement in overall system functioning. This will deliver lower cost, higher levels of safety, security, quality and, increasingly, lower environmental impact, where there is an increasing focus on operational as well as technological solutions. This model is adapted to address aviation systems that are much more distributed. This is not just because of the requirement to address general aviation, but also because there is a proliferation of different users of airspace flying in increasingly diverse vehicles over the coming decades such as business, services, leisure and other industrial users. These exploit new materials and novel technical innovations.

The next generation of automation is based on relatively independent information systems in which both people and technologies perform a much-transformed role. It has much more intelligence than current automation and is potentially distributed across the whole aviation system - air and ground. A big challenge for the next generation of human factors is to design this next generation of automation, ensuring that its operators retain the competences necessary to fulfil service continuity in degraded modes.

The standardisation of information systems and their linkage to multiple sensors and processors all over the system results in stakeholders being deluged by a flood of information. This explosion of information potentiality requires an intense RTD effort to configure effective support for the human in the system, whether passenger, crew, controller, dispatcher, planner or manager. The proliferation of available information in future systems creates the potential to manage and regulate diverse aviation operations in new ways. The gathering, processing, reconfiguring and distribution of all kinds of data makes everyday operations of the system much more transparent in relation to safety, security and performance effectiveness. This gives rise to much smarter management concepts that supply, support, manage, control, monitor and improve the system in all its aspects. It results in new, more effective opportunities to make the operators of the system accountable for the way it is operated, bringing about new models of regulation, including the full cycle of certification, approval, licensing, investigation, etc.
4.7.1 HUMAN-CENTRED AUTOMATION

Human-centred automation is concerned with the design of automation and information systems to support and optimise human roles across the ATS, including air and ground operations and maintenance.

Automation is available to support the human in both normal operations and emergencies and is based on the optimum allocation of functions between the human and machine in order to maximise situation awareness, support decision-making, and enhance performance execution. Information systems support human collaboration across seamless operational concepts throughout the ATS (air and ground).

Preventive maintenance and system upgrades of automated systems and information management systems are facilitated through automated processes and adapted human support systems.

In the operational domain, aircraft, airport and ground handling technologies are integrated to support people in the turn-around process and links to other transport modes.

4.7.2 NEW CREW/TEAM CONCEPTS

New crew and team concepts encompass both the functional interactions of all operators and users of the ATS and their culture. This delivers support optimised performance, monitoring, recovery from stress as well as effective change and evolution of the system.

The diverse dimensions of passenger and personnel culture are understood, measured, analysed so that system change can positively influence cultural evolution to foster system effectiveness in relation to safety and security goals.

Better job design and management results in the optimisation of the Human Performance Envelope to reduce current problems of fatigue, loss of vigilance, poor decision-making, loss of situational awareness or loss of control.

A new crew concept is developed that embraces the whole ATS, enhancing collaboration across professional roles and between organisations. The monitoring of crew/team capacity and subsequent identification and application of corrective measures provides an environment of continuous improvement. Services are designed and provided to address critical incident stress and the psycho-social needs of crew/team/organisation following major disruption or disaster.

4.7.3 PASSENGER MANAGEMENT

Improved passenger management is based on better understanding of the characteristics, behaviours and cultures of passengers and leads to better prediction of threat, management of behaviour and recovery from stress. It is based on a firm understanding of the diverse dimensions of passenger culture built on measurement and analysis. System change can then respond positively to cultural diversity, influence cultural evolution and behaviours with the aim to enhance system effectiveness in relation to safety and security goals.

In particular relating to security, better understanding of the socio-cultural aspects of threat enable improved prediction of terrorist threats or sabotage. Passenger management is also enhanced by better understanding and management of human behaviours during emergencies and supported by the ability to control disruptive behaviour safely. Following major disruption or disaster, services are available that address post-traumatic stress and psycho-social needs of passengers and any members of the public affected.
4.8 Timeline

**Digital society**
- Standards for Safety and Security
- Data management
- Legal framework for data privacy and availability
- Cyber security alerting mechanisms
- Security Management System

**Automation**
- SESAR ATM improvements
- UAS integrated
- Integrated information systems providing better situational awareness
- Systems and personnel monitoring to improve safety and security performance

**Customer experience**
- Risk based screening for passengers and goods
- RFID tracking of cargo and baggage
- Improved management of disruption and congestion

2020
The following figure provides an illustration of the high-level evolution of the capabilities needed to meet the goals of Challenge 4. SRIA Volume 2 provides more detailed information on evolution of the enablers, capabilities and technologies needed to meet this Challenge as well as the metrics used for monitoring progress.

2035

- Fully integrated EU safety data lookup and exchange system
- Multi-modal security approach integrating data across modes
- Commercial aviation systems are adaptive in overcoming vulnerabilities

- Self-healing safety and control systems
- Automation systems for GA
- Commercial single pilot operations
- Automated optimisation and separation of air vehicles
- Automated air traffic operations at medium sized airports

2050

- Defence in depth to potential cyber attack
- Resilient secured global high bandwidth data network
- Global CNS coverage available to all air vehicles

- Full integration of all automated air vehicles
- Autonomous freight operations
- Decentralised interlinked autonomous safety critical systems in operation
- Automated self-correcting capabilities for all critical safety and security systems

- 5 minute processing time in all European air transport embarkation nodes
- Seamless security across transport modes
- Consumer choice is influenced by evidence provided

- Smart personal biometric devices
- 15 minute maximum total queuing and processing time in all European air transport embarkation nodes
Challenge 5

Prioritising research, testing capabilities and education
5.1 Introduction

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.
Europe has the world's leading research infrastructure covering the entire aviation system from wind tunnels through simulation facilities to test aircraft. This infrastructure is organised as research clusters distributed across Europe to facilitate and secure the collaboration of industry, universities and national research organisations. European research is defined, organised and funded in a coherent and coordinated, dynamic and agile way avoiding duplication and inefficiency. It is prioritised towards initiatives resulting from strategic roadmaps defined and agreed by all European stakeholders, satisfying actual needs (industry pull) and potential future demands (technology push). Research programmes and initiatives are established efficiently and effectively. The need for transparency and accountability in publicly funded programmes is balanced against the cost and delay of delivery and the need for protection of intellectual capital.

Comprehensive and consolidated test and validation infrastructure is available in time to support the (r)evolution of vehicles and their seamless integration into an efficient and effective multimodal transportation system. The test and validation capabilities completely integrate the ground and airborne validation and certification processes.

Test and validation facilities are harmonised and interoperable across Europe and include modelling, fast- and real-time simulation and flight-trial systems. The infrastructure capabilities have been defined collaboratively between research organisations, airspace users, air navigation service providers, airports and industry.

Education and training for controllers, pilots and engineers are incorporated into the system and to guarantee success, research and validation initiatives are integrated with education.

Europe’s students in aviation subjects are highly achieving compared to all academic benchmarks. University courses are academically challenging and are designed and continually evolved to support the needs of industry and research. Industry engages actively with European students at all levels both motivating their interest in the sector and stimulating innovation and ideas. At a practical level, education is facilitated by means of collaboration between scientists, engineers, airports, airlines, air traffic controllers and pilots. The entire sector is committed to lifelong learning and continuous education programmes for its workforce through collaboration with universities and research establishments.
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 multi-disciplinary 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.
5.3 The enablers to reach the goals of Flightpath 2050 for Challenge 5

Enablers describe what is needed to achieve the goals. Capabilities describe how the goal can be achieved. The general enablers needed to realise the goals associated with Challenge 5 are as follows.

- **Optimisation of the research and innovation lifecycle**: generates the results needed by industry as well as by a prospering society, with European aviation research considering the complete system, including full life cycle management.

- **R&D infrastructure**: is an elementary pillar of high-technology research and needs to be of highest quality and efficiency, reaching from wind tunnels via iron and copper birds up to experimental aircraft, all organized in a network for the best usability for all stakeholders.

- **Education and workforce**: delivers the quality, the skills and the motivation to be able to meet the challenges of the future. This requires a harmonised and balanced approach covering the entire scope from attracting talents over primary and secondary education to apprenticeship, academia and lifelong professional development.
5.4 Optimisation of the research and innovation lifecycle

Aviation research applies a fully coordinated approach to fulfil Flightpath 2050 goals. Research not only translates into products through innovation, but also stimulates education, and develops, as well as uses, infrastructure. Research generates results needed by industry as well as by a prospering society. European aviation research targets the complete Air Transport System and applies a full life cycle engineering approach.

European research and innovation is defined, organised and funded in a coherent and coordinated way with minimum administrative burden. Transparency and accountability in publicly funded programmes are well-balanced, promoting timeliness, efficiency and the appropriate protection of intellectual capital. Programmes are focused on common objectives and roadmaps shared by all stakeholders across the entire supply chain. Roadmaps allow the prioritisation of research. The full innovation chain is applied consistently from ideas through fundamental and applied research, technology development and demonstration, commercialisation and market development to market entry. Research is undertaken by the relevant partnerships, including industry, research institutes, universities and government. Appropriate levels of funding, not least by the European Framework Programme for Research and Innovation, and continuity is assured. Public-private-partnerships (PPPs) are established as necessary.

5.4.1 Research and Innovation Chain

The sector is organised to sustain the full research and innovation chain. This includes mechanisms for small and medium enterprises (SMEs) to link with higher tier suppliers without any penalty for sub-contracting. Research work with achieved previously maturation in its TRLs is continued and intensified with particular emphasis on medium and high levels which are specifically focused on improving components for existing aircraft. Fundamental aeronautics research is coherent with more applied research and makes use of the European Research Council’s scheme. In the short-term, attractive and efficient research instruments are put in place, which ensure continuity between research on promising breakthrough concept, their validation by focussed RTD actions and finally their demonstration in an integrated environment.

The gap between research results and innovative products and services is bridged, with special emphasis on intellectual property. This results in the seamless transfer of fundamental research to practical application/innovation. Research establishments are a natural bridge between basic research, conducted mainly by academia on the basis of actual industrial needs, and applications. Citizens and passengers have better insight in and knowledge about the (r)evolutionary changes needed to prepare the ATS of tomorrow. Their understanding of reasons...
and benefits ensures widespread acceptance and, ultimately, trust.

Mechanisms are provided at European level for targeted research and technology impact assessment and evaluation for the entire aviation sector as well as for technology watch programmes. These tools allow the identification of new sector specific and key enabling technologies, processes, and regulatory and institutional approaches from other sectors and geographies. In the short-term, a technology watchtower (a technology assessment network) is established to prospect rest-of-the-world technologies.

Harmonisation between technology evolution in aviation and in other correlated sectors enables spin-in from and cross-fertilisation with innovations in other sectors, such as communications (mobile web, travel search engine providers). It also incentivises the aeronautical world to be more adaptive to the very fast evolution of IT technologies (c.f. the current aeronautical evolution on 10-year time scale versus IT technology evolution on a yearly time scale).

OEMs and tier one suppliers set ambitious requirements to promote technology development and competition in the different tiers of the supply chain to enhance the overall competitiveness in the OEM’s supply chain and to keep tier one competitive worldwide.

In the short-term an operational model is developed to analyse aviation processes to assess the full scope of the aerial vehicle and its operation in the aviation system. In the medium-term and long-term possible solutions and applications are implemented.

5.4.2 CLUSTERS OF EXCELLENCE

Multidisciplinary clusters of excellence for research and innovation are established to achieve common technology goals (outcome of a common strategy to address societal issues). They ensure that the appropriate organisations are tackling activities at the appropriate level in the innovation chain. There are agreed processes to use infrastructure in research as well as in education. Research projects and infrastructure are used to attract the workforce. In addition, a knowledge management and transfer environment is created protecting intellectual capital and competitive advantage. In this environment industry can open books to researchers concerning the key industry strategic issues. Academia is able to federate research on the basis of actual industry needs and deliver the excellence of fundamental science with the right market-oriented applications.

The successful research and innovation lifecycle is supported by a set of generic capabilities, including a world-class aeronautical and air transport research and innovation capability. In addition, dedicated research capability offers strategic research as well as development support to policy makers and operational end user organisations (e.g. airlines, airports, Air Navigation Service Providers (ANSPs), ground operators). Education of researchers is provided jointly by industry, research establishments and academia.

Appropriate tools and funding instruments are available for a range of activities including: technology development, technology demonstration, technology watch and evaluation, impact assessment, system integration and demonstration.
5.5 Infrastructure

Research and development infrastructure is an indispensable tool to achieve a decisive competitive edge in developing sustainable aviation products and services that meet the needs of EU citizens and society. Appropriate core capabilities are available and accessible. Infrastructure and the associated workforce are vital assets, which are maintained and further developed in a focused, efficient and cost-effective manner. Suitable access to these facilities enables knowledge transfer across Europe and facilitates continuity from blue sky research to innovation in products and services for the benefit of Europe.

Strategic aviation infrastructure is of the highest quality and efficiency, providing the basis for world-class research and competitive product development while supporting education. It ranges from wind tunnels via iron and copper birds up to experimental aircraft and simulation capabilities for in-flight and airport operations. Infrastructure is organised in a network for the best usability of all stakeholders. The data quality and operational efficiency of European aviation infrastructure helps industry to minimise risks and development costs, and helps society to determine the impact of aviation in benefits such as fast transport as well as in penalties such as impact on the atmosphere.

The Flightpath 2050 goals are achieved such that:

- Europe has the world’s leading research infrastructure. This infrastructure is built on existing facilities, which are maintained, together with the coordinated development of new infrastructure.

- The infrastructure capabilities have been defined collaboratively by all stakeholders.

- Facilities are organised as research clusters networked across Europe to facilitate and secure the local collaboration of industry, universities and national research organisations.

- Comprehensive and consolidated test, demonstration and validation infrastructure is harmonised, interoperable and available across Europe. This supports the (r)evolution of aerial vehicles and their seamless integration into an efficient and effective multimodal transportation
system. They include modelling, fast and real-time simulation and flight-trial systems.

- These capabilities integrate the ground and airborne processes.

## 5.5.1 EUROPEAN RESEARCH AND INNOVATION ROADMAP

A **strategic roadmap for European research and development infrastructure** is published. It covers the entire aviation system including existing and new infrastructure, and clarifies the roles and responsibilities for the infrastructure. It is developed and maintained continuously by all stakeholders, identifying and providing an inventory of existing and evolving infrastructure based on needs derived from Flightpath 2050. The roadmap includes criteria for classification (strategic, key, common) and the economic outlook for each infrastructure item. Utilisation is one important indicator but not the overriding metric for justifying the need for a particular infrastructure. The roadmap is used as the basis for selection of the optimum infrastructure supported by a coordinated investment plan, taking into account gaps, duplication and overcapacities.

The roadmap results in a network of **physical and virtual testing and certification infrastructure** to ensure that competent workforce, reliable and interoperable facilities as well as standardised processes and data exchange actually enable maximum time-cost-quality benefits. The **organisation of infrastructure into a European network or clusters supported by the appropriate legal framework allows**, for example, the trading of wind-tunnel models securely or test facility access through a voucher system to stimulate the optimal use of facilities while avoiding issues relating to IPR and competitive advantage. Infrastructure **funding** from usage fees, publicly funded programmes as well as national and EU institutional funding (including the use of structural funds via access vouchers) provides reliable revenues to sustain the strategic infrastructure. An appropriate business model and regulatory framework has to be developed to realise the usage of funding from these sources.

## 5.5.2 ACCESS TO RESEARCH INFRASTRUCTURE

**Processes for using infrastructure** are in place for research, product development and education. This supports research and education purposes as well as providing **arrangements to ensure barrier-free access by SMEs** to research and testing infrastructure.

**Joint activities involving multiple stakeholders** are facilitated by PPPs whenever appropriate and cover the entire innovation chain from basic to applied research. Proper handover of results to the next stakeholder is assured upwards through the innovation chain. Examples of such joint activities include:

- Test and simulation of crisis management systems to cover disruptive events (weather, volcano, etc.).

- Provision of a European Aviation Computer Centre for multidisciplinary analysis.

- Optimisation and aviation infrastructure for MRO and product life cycle management.

- Establishment of a European X-aircraft fleet for experiments with and on aircraft.

Research results enhance the **overall simulation and modelling capability** in the areas of multi-functional simulation from the future project phase down to the development and manufacturing phase. This capability permits significant reduction of the physical test phases (ground and flight tests) and hence reduces development and certification time. **Large dimension simulations** allow rapid design iteration and optimisation.
involving all system levels and across all disciplines from flight physics to physical design. These capabilities permit the full use of the virtual reality:

- For emergence of radically new technical vehicle and system concepts and materials design.
- In design, testing and certification to minimise the development effort.
- In manufacturing and support in an extended enterprise framework.

There is large-scale co-operation in science, code development and high power computing. The main topics of this include:

- Improved and validated fluid dynamics, aerodynamic control, combustion, noise and thermal modelling based on high performance computation, covering all needs for the aircraft and its engines, external and internal.
- Methods and tools facilitating evaluation of aircraft and engine configurations.
- Results from demonstration, allowing to assess not only improvements in vehicle development but also to verify and validate new modelling techniques.
- Improved structural damage and failure analysis, structural modelling methods, including multi-physics simulation capability and better material modelling, facilitating higher accuracy and reliability in design optimisation. This is particularly important considering the need for new materials which in turn may require method development for structural simulation as well as material modelling and characterisation.
- A large scale and complete air/ground traffic simulation tool to allow the definition of optimised operations whilst minimising travel distance and time, and specifying the required features of each element of the traffic management (vehicle, ground services, etc.).

5.5.3 TECHNOLOGY DEMONSTRATION

Support is provided to ensure the availability of high level European capabilities for technology demonstration. These include ground test facilities, flight test beds, reduced scale flight demonstrators and technology integration platforms. There are means to demonstrate, in-flight, the integration of several breakthrough technologies in one platform. Dedicated test aircraft are maintained in the short-term and enhanced and adapted to meet evolving needs in the medium-term. In the long-term a new configuration of test aircraft is available (e.g. x-plane). Potentially, large scale demonstrators are put in place to validate the simulation capabilities with respect to unconventional configurations.
5.6 Education and workforce

One of the main enablers for Europe to maintain leadership in aviation is an excellently educated, qualified, experienced and motivated workforce. As a result, people working in this sector are dedicated, driven and inspired to create and foster the use of new technologies in the next generation of air transport. In the light of the many challenges that the world faces in terms of environment and scarce resources, aeronautical technology needs both gradual and radical innovations. This requires the education and attraction of brilliant young minds as well as fostering, building on and extending the knowledge of the existing workforce.

A fully integrated European aviation education system delivers the required high-quality workforce and provides lifelong learning. To achieve this, aviation offers attractive job opportunities to professionals as well as to workers without discrimination and independent of their educational background, nationality, age or gender. Attractive jobs, as well as fascinating products, make aviation the number one career aspiration. Europe’s skilled workforce is in demand worldwide.

The excellent relations and co-operation of academia, industry and research establishments resulting from years of collaborative research enables this leap forward and facilitates investment. Education and employment initiatives ensure Europe’s position as a world leader in aviation and contribute to solving the societal problem of, on one hand, the increased demand for air travel and, on the other hand, the global environmental and resource challenges threatening the air transport sector.

The following goals extended from Flightpath 2050 are not limited to engineers but also apply to everyone working in the air transport sector: scientists, pilots, air traffic controllers, technicians, airline and airport administrators, state administrators, and policy makers. The specific goals are to ensure that:

- Europe’s students are attracted to careers in aviation and perform highly. Courses offered by European Universities are academically challenging and adapted continuously to support and match the evolving needs of the sector research (establishments) and administrations. Educational policies across the EU motivate students to pursue further studies in science, technology and mathematics to ensure a steady supply of talent for a first class workforce. The aviation community engages actively with European students from the earliest age.

- Vocational courses, for example for pilots, air traffic controllers and technicians are equally attractive, challenging and result in excellent performance.

- A network of multi-disciplinary technology clusters is created based on collaboration between industry, universities and research establishments.

- The aviation community is committed to lifelong learning and continuous education thus promoting interest in the sector and stimulating innovation.
5.6.1 MATCHING THE NEEDS

Air transport professionals are critical for the continuing development of the air transport sector and for the aviation industry. Consequently, Europe sets provisions to ensure that a reliable source of such personnel is available over all timeframes. Air traffic controllers, air transport pilots and a wide range of engineers, technicians and administrators are necessary to keep the whole aviation system on an upward trajectory in Europe. As one of the leading regions for aviation in the world, Europe is at the forefront of academic and non-academic (higher) education for aviation professionals. Higher education is based on the adaptation of curricula based on the evolution of knowledge, language and (soft) skill requirements derived from ICAO. The curricula are designed based on a common understanding of the balance between multi-disciplinary and in-depth knowledge, such as, for example, common language recommendations, the T-shaped professional and the Conceive-Design-Implement-Operate (CDIO) philosophy. This ensures that scientists of the future are capable of integrating interdisciplinary skills of a technological, human and social nature. Also more detailed requirements such as inclusion of a flight test, hands-on experience, and a minimum amount of essential, aeronautics related knowledge are included. Curricula are accredited by the appropriate professional bodies, which also provide guidelines on content as part of the accreditation process. These guidelines reflect input and best practices from aviation stakeholders, via strong relations with their human resource management departments. Accreditation provides an
acknowledgement by the aeronautics industry of the value of the qualifications.

Academic education is based on standard structures for higher education in three stages, from the first tier (Bachelor studies), the second, intermediate tier (Master studies) to the third tier (Doctoral studies). The best students are attracted by establishing a master track for outstanding students. This provides for a specially selected, international cohort to participate in courses developed and given by different academia. There is world-wide coverage, attracting top students facilitated by the Erasmus-Mundus scheme. In addition to a Master’s degree, this challenging programme provides successful students with a special certificate of excellence.

At the professional level, there is a common definition and uniform high quality of European Aviation Engineering Education that includes accreditation. This is implemented and overseen by an appropriate European level organising body.

A long-term employment plan for the aviation sector is the foundation for ensuring the availability of high-qualified aviation employees in Europe. This plan is based on a firm understanding of the current and future needs for the workforce in the sector as well as demographic analysis of the current aeronautical workforce.

The employment plan is used as the basis to consolidate and secure the education system. Across-European-border cooperation programme is established to identify and apply best practice in aviation education, learning lessons from other regions and hence strengthening the European position.

Experience and knowledge management mechanisms are in place to prevent the loss of experience when employees retire and to secure continuity of European aviation skills. These are supported by Europe-wide processes which define the use of the deep knowledge of the experienced and retired employees, in research, education and innovation.

5.6.2 ATTRACTING TALENT

To attract both students and workers the aviation sector is seen as exciting, challenging and financially attractive as a work option. The image of the sector is enhanced by profile-raising targeted at specific audiences using various mechanisms, including innovative projects for students and professionals, dissemination of exciting project results, and networks to attract top talent from other parts of the world to study and work in Europe. In addition, the design and build of actual flying test-beds and demonstrators as concept models is used to demonstrate the direction of envisaged developments. The ideas and vision of the European Aviation Sector are publicised widely to appeal to new talent as well as the general public.

The availability of a workforce with sufficient depth and breadth is facilitated by the provision of attractive employment with promising career prospects. Aviation job characteristics include a high standard of education, non-discrimination and equal opportunities, scope for advancement (promotion), job security, attractive compensation, flexible working to promote work-life balance and status. In addition, this attractiveness is also increased by ensuring high quality of work for lower-qualified jobs by using advanced tools based on virtual reality. Mobility management is applied to ensure that workers with the appropriate skills are available in the right place at the right time.

Providing the required workforce is, of course, contingent on the education and training systems in place. Educational policies across the EU motivate students to pursue further studies in mathematics, science and technology. The aviation com-
Community contributes to this global effort by outreach actions with the final objective of attracting the students to aviation careers. These outreach actions include:

- The development of didactic material for schools; proposing experiments based on aviation challenges.
- Contacts between students, teachers and aviation professionals.
- Visits to school labs, research centres and industry.
- Websites with outreach resources; aviation career description kits for career advisers.
- EU competitions at different levels (pre-school/school/university) addressing interesting aviation issues.
- Aeronautic events.
- Marketing aviation education using all media, especially social media.
- Flying and hands-on experience.

A policy is in place to promote diversity for talent. This policy ensures an adequate supply of scientists and engineers. Furthermore, diverse working teams are balanced and rich in terms of perspectives and approaches. European policy is also designed to attract top talent from other parts of the world. Fellowships are offered to talented students to pursue their study in European Universities and to encourage them to stay working in Europe after their studies.

Teaching itself is based on best practice and optimum use of technology, for example through the use of video, touch technology, study material on mobile devices as well as research infrastructure. Serious gaming, linked to aeronautics concepts, based on rewarding/motivating schemes is available. Using modern, open source programs, e-learning, distance learning, open-courseware and tele-presence are techniques applied that correspond best to the technological world in which young people are growing up. An overview of these tools and methods, as well as examples and educational material, is provided by an established network. Students also have an easy and affordable access to the research infrastructure.

The organisation of competitions and prizes for primary and high schools is used as a major dissemination and motivation tool. These competitions are organised at regional or European levels to add an attractive multi-cultural aspect and are supported by industry and learned societies.

Excitement about the aviation sector is also fostered by publicising the latest developments in technology and establishing a link with mathematics, science and
technology courses, to emphasise their relevance. Research projects funded by the European Commission include dissemination activities focused on young people, e.g. by proposing simplified experiments linked to the project, by serious gaming or by providing an attractive explanation.

Attraction of the European aviation workforce starts at the primary education stage. This is facilitated through the establishment of a community of aviation professionals at European level, strongly supported by existing associations at regional level. This community communicates, collaborates and develops projects involving primary and high school students (ages from six to 17/18 years old) and their teachers. This centralises, provides visibility and disseminates the best practices developed in each country or in the frame of European projects. A website with outreach resources is an essential tool to provide the teacher and student communities with quality resources to understand and to perform experiments on the challenging aspects of aeronautics. This website provides on-line communication with aviation professionals and is augmented by the provision of internship opportunities for high school teachers to experience research and provide real-world perspectives and motivation in their teaching and their applications.

5.6.3 TECHNOLOGY CLUSTERS OF UNIVERSITIES, INDUSTRY AND RESEARCH ESTABLISHMENTS

Partnerships between research, universities and industry on education are established, including opportunities for student secondments to industry. These partnerships facilitate exchange of personnel between research, university and industry.

There is extensive cooperation between industry, research establishments and academia based on internships for students in industry and research establishments across Europe. Staff is exchanged between industry, research establishments and academia and research infrastructure is used in education. There is also much greater interaction with aircraft engineering, as air transport systems become more and more integrated from an operational point of view. This interaction is achieved thanks to Centres of Excellence for all professions in aviation.

5.6.4 LIFELONG LEARNING

There is a register of continuing professional development with accredited qualifications to support changes of career path, meet evolving requirements and develop a culture of lifelong learning. This is supported by the availability of teaching/training systems adapted to the boundary conditions of educated and experienced personnel e.g. e-learning (engineers, technical staff, air transport professionals ATC, ATM, pilots, MRO technicians).
the X-prizes is used as a motivational tool for professionals, students, pioneers and entrepreneurs and, also, to highlight the attractiveness of the sector.

**5.6.5 ORGANISATION AND IMPLEMENTATION**

The relevant parties and organisations continue and extend their role and activities:

- For the Europe-wide harmonisation of aviation related curricula, universities and their associations active in this area play a key and pro-active role.

- Several outreach activities are organised and coordinated successfully by different parties competent in this field. Research establishments, universities as well as aviation related associations on European and national level also play an active role and contribute by their capabilities, in particular by setting-up, running and harmonising work on School Labs. The necessary co-ordination, exchange of best practices and outreach materials are ensured Europe-wide.

- For the clustering of training for aviation professionals throughout the different aviation sectors and the related lifelong learning measures, initiatives and co-ordinated efforts are applied at European level in addition to those at national and local level.

Public institutions and authorities on European and national level ensure continuity of these activities and bring the existing, often locally organised activities to an equivalent European level by the appropriate supporting measures. The joint task is to encourage and monitor continuously the progress of curriculum harmonisation, the exchange of best education practices, outreach measures, continuous learning and forming knowledge exchange clusters. This ensures a Europe-wide exploitation of the results of the projects set up with specific goals.
5.7 Timeline

2020

Optimisation of the research and innovation lifecycle
- Organisation of research & innovation chain, with links from SMEs to higher tier suppliers
- First Technology Evaluator & Technology Impact Assessment Process (Clean Sky/SESAR level)

Infrastructure
- Roadmap for R&D infrastructures development
- Voucher access system for SMEs
- HPC local simulation
- Passenger-centred air transport simulator

Education and workforce
- European Aviation Engineering Academy creation
- Flying demonstrators designed & built during education
- European Aviation X-Prize (EAX) organisation
The following figure provides an illustration of the high-level evolution of the capabilities needed to meet the goals of Challenge 5. SRIA Volume 2 provides more detailed information on evolution of the enablers, capabilities and technologies needed to meet this Challenge as well as the metrics used for monitoring progress.

2035

- Harmonised knowledge management & transfer environment
- Process to use infrastructure also for education
- Integrated Technology Evaluation & Technology Impact Assessment
- Timely upgraded European assets
- Crisis management of disruptive events
- HPC computation structure
- Multimodal transport simulation
- Single European aviation education accreditation
- One-point access for courses from academics to technicians
- Lifelong learning tools

2050

- Seamless transfer of fundamental research to practical application & innovation
- European Technology Evaluator & Technology Impact Assessment
- Fully networked test environment
- Capabilities for zero-emission air transport
- Fully networked HPC resources
- Net of facilities for virtual certification
- Fully integrated European aviation education system
- Several demos built by students at large scale
- 10 challenging EAX-Prizes won
- Workforce in aviation educated and trained by industry, research establishment and university
Since the first steps of European cooperation, aviation has been the pioneering sector moving from a formerly widely fragmented patchwork of local, regional and national players and interests into a harmonised, integrated and well-coordinated pan-European high-technology sector. It provides Europe with prestige, wealth, sophisticated employment opportunities and essential societal and economic benefits.

The demands on and challenges set out in this SRIA for tomorrow’s European aviation sector go far beyond the traditional borders. To achieve the Flightpath 2050 goals, European aviation research and innovation must:

- **Pave the way to truly intermodal transport**, with integrated and resilient mobility concepts for the traveller and freight. This requires to understand societal and market needs, to develop innovative travel management processes and tools with new and improved air traffic management services, relying increasingly on intelligent information systems.

- **Maintain global leadership** for a sector that is highly advanced and anticipated to grow, based on:
  - Innovative vehicles, products and services, supported by efficient manufacturing.
  - Efficient and effective **policy, regulatory and certification frameworks**, which ensure a global level playing field and allow European industry to prosper and compete fairly under market conditions.

- Incentives, accompanied by **long-term research, technology and innovation programmes that provide continuity** across R&T 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. This relies on optimised vehicles and operations, **sustainable and affordable alternative energy source**, the full understanding of the impact of aviation on the environment accompanied by the proper regulatory framework.

- **Maintain the sector’s safety track record** and enable solutions to increasing security risks to be ‘built-in’ to future designs. In this new total transport system – integrated, automated and with seamless door-to-door service - safety and security are assured by a **system-wide safety and security management** approach. This is implemented coherently from design, manufacturing and certification phases, as well as across air vehicle operations. There is a better understanding of human factors related to the new roles of passengers and transport operators and optimised synergies between humans and automated systems.
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.

ACARE stakeholders are committed to continue playing a pivotal role in providing the means for collaboration and cooperation at a European and global level.

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.

- 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 based on an education system which provides profiles that are tailored to the needs of the European aviation sector.
Annex A: Detailed environmental targets

SETTING TARGETS FOR CO₂ EMISSIONS:

The targets for CO₂ emissions as set originally in the SRA for 2020 were split into component areas covering, broadly: engine, airframe, systems, ATM and operations. However, in covering such a long horizon as in the SRIA towards 2050, there is a need to refine the breakdown which now recognises the aircraft’s different energy needs (for flight including all on-board systems and services), the power and propulsion provision efficiency, ATM and infrastructure, and non-infrastructure driven (airline) operations. This split follows the IATA 4 pillar strategy more closely and also enables the stakeholders in the overall aviation efficiency equation to recognise separate areas of responsibility and activity.

The table below breaks down the efficiency targets defined along the component areas. The AGAPE exercise, performed to inform on the mid-term progress towards the 2020 goals, is included. The SRA goals and the AGAPE forecasts have been re-calibrated to reflect the SRIA breakdown. It is important to recognise the factoring effect in the methodology. Thus, the complete aircraft performance in 2035, comprised of aircraft energy efficiency plus propulsive efficiency, would be 0.70 x 0.70 or 49% of 2000 levels.

<table>
<thead>
<tr>
<th>Goals and Key contributions</th>
<th>2000 (Reference)</th>
<th>2020 (Vision)</th>
<th>2020 (AGAPE)</th>
<th>2020 (SRIA)</th>
<th>2035 (SRIA)</th>
<th>2050 (SRIA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ objective vs 2000 (“HLG”)</td>
<td>-50%**</td>
<td></td>
<td></td>
<td></td>
<td>-75%**</td>
<td></td>
</tr>
<tr>
<td>CO₂ vs 2000 (kg/pass km)*</td>
<td>-50%</td>
<td>-38%</td>
<td>-43%</td>
<td>-60%</td>
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<tr>
<td>Airframe energy need (Efficiency)</td>
<td>1</td>
<td>0.75</td>
<td>0.85</td>
<td>0.8</td>
<td>0.7</td>
<td>0.32</td>
</tr>
<tr>
<td>Propulsion &amp; Power energy need (Efficiency)</td>
<td>1</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>ATM and Infrastructure</td>
<td>1</td>
<td>0.88</td>
<td>0.95</td>
<td>0.93</td>
<td>0.88</td>
<td>0.88</td>
</tr>
<tr>
<td>Non Infrastructure-related Airlines Ops</td>
<td>1</td>
<td>0.96</td>
<td>0.96</td>
<td>0.96</td>
<td>0.93</td>
<td>0.88</td>
</tr>
</tbody>
</table>

* comparison with same transport capability aircraft and on a same mission in term on range and payload
** ACARE 2020 and ACARE 2050 High Level Goals for airframe, engine, systems and ATM/Operations
For 2050, no breakdown between airframe and propulsive and power efficiency is given to avoid unnecessary constraints around possible solution directions.

The Flightpath 2050 climate change goal of 75% reduction in CO₂ emissions per passenger kilometre has been designed to support the “ATAG goals”, which all aviation industry stakeholders (manufacturers, airlines, airports and air navigation service providers) have committed to in the forerun to the Copenhagen Climate Conference in 2009. These goals are:

• an average annual fuel efficiency improvement of 1.5% in the global flying fleet between 2009 and 2020,

• followed by the stabilization of net CO₂ emissions levels (“carbon-neutral growth”) from 2020, including economic measures,

• and ultimately reducing net CO₂ emissions by 50% relative to 2005 in 2050.

Clearly, the ATAG goals are based on considerations which are different to the Flightpath 2050 goal: the latter applies to new aircraft with state-of-the-art technology, whereas the ATAG goals refer to the whole global flying fleet (all ages and including air traffic growth). They include CO₂ savings through the use of biofuels as well as economic measures, such as carbon offsets and emissions trading. The Flightpath 2050’s 75% goal can only support the ATAG goals in the technology and operations domain, whereas additional means are needed to meet the ATAG goals. In particular, the Flightpath 2050 goal is independent from economic factors such as the available amount of aviation biofuels; it thus includes technical efficiency improvements for aircraft and ATM, but excludes savings from a smaller or larger use of biofuels.

### SETTING TARGETS FOR NOₓ EMISSIONS AND LOCAL AIR QUALITY:

The impact of NOₓ emissions can be split between climate change effects and local air quality. The 2050 goal for 90% reduction in NOₓ emissions (below) will require radical new technologies alongside improved low NOₓ combustion, higher engine efficiency, whole air vehicle weight reduction, and optimized flight operations. The 2050 Subsidiary NOₓ goal for local air quality is a 75% reduction margin from CAEP6 level particulate matter emissions also contribute to local air quality. These local air quality issues will be addressed through low NOₓ combustion, higher engine efficiency and by 2020, zero-emissions taxiing.

<table>
<thead>
<tr>
<th>NOₓ objective vs 2000 (“HLG”)</th>
<th>at 2020</th>
<th>2035 at</th>
<th>at 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cruise NOₓ vs 2000 (kg/pass km)*</td>
<td>- 80%**</td>
<td>- 84%</td>
<td>- 90%**</td>
</tr>
<tr>
<td>LTO NOₓ (margin to CAEP6)</td>
<td>- 60%</td>
<td>- 65%</td>
<td>-75%</td>
</tr>
</tbody>
</table>

* comparison with same transport capacity aircraft on a same mission in terms of range and payload
** ACARE 2020 and ACARE 2050 High Level Goals for aircraft/engine/ATM
SETTING TARGETS FOR NOISE EMISSIONS

The perceived noise emissions of flying aircraft and rotorcraft should be reduced in 2050 by 65% relative to the 2000 situation. This goal should be achieved through a significant and balanced research programme aimed at developing novel technologies and enhanced low noise operational procedures, complemented by a coordinated effort providing industry, airports and authorities with better knowledge and impact assessment tools to ensure that the benefits are effectively perceived by the communities exposed to noise from air transport activities.

More specifically, this amounts to developing technological and operational solutions by 2050, aimed at a 15dB reduction per fixed wing aircraft operation (departure and arrival) with a medium-term target of 11dB by 2035.

Concerning rotorcraft, the long-term 2050 target is to reduce the noise footprint area by 65% (by noise reduction at the source as well as noise abatement procedures) relative to a generic aircraft representing the year 2000 rotorcraft fleet, for representative mission segments of take-off, cruise, and landing. The associated medium-term target is 55% by 2035.
## Annex B: Definition of terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>4D</td>
<td>Four-Dimensional</td>
</tr>
<tr>
<td>ACARE</td>
<td>Advisory Council for Aviation and Research and Innovation in Europe</td>
</tr>
<tr>
<td>AGAPE</td>
<td>ACARE Goals Progress Evaluation</td>
</tr>
<tr>
<td>ANSP</td>
<td>Air Navigation Service Provider</td>
</tr>
<tr>
<td>ATC</td>
<td>Air Traffic Control</td>
</tr>
<tr>
<td>APU</td>
<td>Auxiliary Power Unit</td>
</tr>
<tr>
<td>ATA Chapter</td>
<td>Air Transport Association Chapter, providing a common referencing standard for all commercial aircraft documentation</td>
</tr>
<tr>
<td>ATAG</td>
<td>Air Transport Action Group</td>
</tr>
<tr>
<td>ATM</td>
<td>Air Traffic Management</td>
</tr>
<tr>
<td>ATS</td>
<td>Air Transport System</td>
</tr>
<tr>
<td>BLI</td>
<td>Boundary Layer Ingestion</td>
</tr>
<tr>
<td>Capability</td>
<td>Knowledge and processes to carry out any kind of work needed in the aviation sector, from education through research to products, operations and business</td>
</tr>
<tr>
<td>CCP</td>
<td>Central Case Design Project</td>
</tr>
<tr>
<td>CDIO</td>
<td>Conceive, Design, Implement, Operate</td>
</tr>
<tr>
<td>CDM</td>
<td>Collaborative Decision Making</td>
</tr>
<tr>
<td>Citizen</td>
<td>Citizens are concerned to varying degrees about how transportation, including aviation, affects them from the perspectives of leisure, employment, economics, air quality, noise, or related factors. Some citizens are passengers</td>
</tr>
<tr>
<td>CNS</td>
<td>Communications, Navigation and Surveillance</td>
</tr>
<tr>
<td>COTS</td>
<td>Commercial Off The Shelf</td>
</tr>
<tr>
<td>CROR</td>
<td>Contra-Rotating Open Rotor</td>
</tr>
<tr>
<td>Customer</td>
<td>A passenger on a journey or the movement of freight by a freight operator</td>
</tr>
<tr>
<td>EASA</td>
<td>European Aviation Safety Agency</td>
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<tr>
<td>EBRD</td>
<td>European Bank for Reconstruction and Development</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
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<tr>
<td>EIB</td>
<td>European Investment Bank</td>
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<tr>
<td>EIF</td>
<td>European Investment Fund</td>
</tr>
<tr>
<td>EMC</td>
<td>Electromagnetic Compatibility</td>
</tr>
<tr>
<td>Enabler</td>
<td>A technology or process that is required to reach a specific goal</td>
</tr>
<tr>
<td>ETS</td>
<td>Emissions Trading Scheme</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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<td>--------------</td>
<td>-----------------------------------------------------------------------------</td>
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<tr>
<td>Ex-Im</td>
<td>Export-Import</td>
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<tr>
<td>GATS</td>
<td>General Agreement on Trade in Services</td>
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<tr>
<td>GBAS</td>
<td>Ground-Based Augmentation System</td>
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<tr>
<td>General Aviation</td>
<td>Civil aviation operations other than a commercial air transport operation or an aerial work operation.</td>
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<tr>
<td>GHG</td>
<td>Greenhouse Gas</td>
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<tr>
<td>GNSS</td>
<td>Global Navigation Satellite System</td>
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<tr>
<td>GoP</td>
<td>Group of Personalities</td>
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<tr>
<td>HMI</td>
<td>Human Machine Interface</td>
</tr>
<tr>
<td>HR</td>
<td>Human Resources</td>
</tr>
<tr>
<td>HW</td>
<td>Hardware</td>
</tr>
<tr>
<td>ICAO</td>
<td>International Civil Aviation Organization</td>
</tr>
<tr>
<td>ICNS</td>
<td>Information, Communications, Navigation and Surveillance</td>
</tr>
<tr>
<td>ICT</td>
<td>Information and Communications Technology</td>
</tr>
<tr>
<td>Innovation</td>
<td>The creation of better or more effective products, processes, technologies, or ideas that are accepted by markets, governments and society. Covers TRLs 7 to 9</td>
</tr>
<tr>
<td>IPR</td>
<td>Intellectual Property Rights</td>
</tr>
<tr>
<td>Journey</td>
<td>The time spent by a customer in moving door to door achieving the objective of reaching a destination by the use of integrated transportation ‘modes’</td>
</tr>
<tr>
<td>JTI</td>
<td>Joint Technology Initiative</td>
</tr>
<tr>
<td>MRL</td>
<td>Material Requirements List</td>
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<tr>
<td>MRO</td>
<td>Maintenance, Repair and Overhaul</td>
</tr>
<tr>
<td>MSPR</td>
<td>Multi-Static Primary Radar</td>
</tr>
<tr>
<td>MST</td>
<td>Mathematics, Science and Technology</td>
</tr>
<tr>
<td>MTOW</td>
<td>Maximum Take-Off Weight</td>
</tr>
<tr>
<td>NDT</td>
<td>Non-Destructive Testing</td>
</tr>
<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer</td>
</tr>
<tr>
<td>Passenger</td>
<td>A traveller whose journey includes the aviation mode and their priorities are numerous like cost, time, flexibility, comfort, leisure with the inherent ambiguity brought by the Citizen side of their personality (price, noise, pollution, etc.)</td>
</tr>
<tr>
<td>PPP</td>
<td>Public Private Partnership</td>
</tr>
<tr>
<td>QSTOL</td>
<td>Quiet Short Take-Off and Landing</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
</tr>
<tr>
<td>R&amp;I</td>
<td>Research and Innovation</td>
</tr>
<tr>
<td>R&amp;T</td>
<td>Research and Technology</td>
</tr>
<tr>
<td>REACH</td>
<td>Registration, Evaluation, Authorisation and Restriction of Chemicals</td>
</tr>
<tr>
<td>RF</td>
<td>Radiative Forcing</td>
</tr>
<tr>
<td>RTD</td>
<td>Research and Technology Development (covers the range TRL 0 to 6)</td>
</tr>
<tr>
<td>Safety</td>
<td>Safety is the state in which the risk of harm to people or property damage is reduced to, and maintained at or below, an acceptable level through a continuing process of hazard identification and risk management.</td>
</tr>
</tbody>
</table>
### Safety Management
The approach to managing safety, including the necessary organizational structures, accountabilities, policies, procedures and technologies

### Security Management
Safeguarding civil aviation against acts of unlawful interference, with the prime objective to protect the safety of passengers, crew, ground personnel and the general public. Aviation security is to protect human beings, goods and infrastructures against acts of unlawful interference

### Security Management
The approach to managing security, including the necessary organizational structures, accountabilities, policies, procedures and technologies

### SES
Single European Sky

### SESAR
Single European Sky Air Traffic Management Research

### SME
Small or Medium size Enterprise

### SOA
Self-Organising Assembly

### SRA
Strategic Research Agenda

### SRIA
Strategic Research and Innovation Agenda

### SVTOL
Short Vertical Take-Off and Landing

### SW
Software

### SWIM
System Wide Information Management

### Traveller
A member of society undertaking a journey in the transport system

### TRL
Technology Readiness Level. The development of technologies for aeronautic and air transport products requires their validation and demonstration through a range of Technology Readiness Levels. This “de-facto” standard of TRL levels is used as a means of managing innovation risk, up to TRL6 which is widely considered the end of the technology development cycle: TRL7-9 then addresses the product development cycle

| TRL 1. | Basic principles observed and reported |
| TRL 2. | Technology concept and/or application formulated |
| TRL 3. | Analytical and experimental critical function and/or characteristic proof-of-concept |
| TRL 4. | Component and/or breadboard validation in laboratory environment |
| TRL 5. | Component and/or breadboard validation in relevant environment |
| TRL 6. | System/subsystem model or prototype demonstration in a relevant environment (ground or in-flight) |
| TRL 7. | System prototype demonstration in-flight |
| TRL 8. | Actual system completed and “Flight qualified” through test and demonstration (ground or in-flight) |
| TRL 9. | Actual system “Flight proven” through successful operations |

### UAS
Unmanned Aerial System

### UAV
Unmanned Air Vehicle

### UHBR
Ultra-High Bypass Ratio

### WAM
Wide Area Multilateration

### WTO
World Trade Organization

### X- aircraft
Experimental Aircraft
For further information

www.acare4europe.org