Lucht- en Ruimtevaart Nederland

TOPSECTOR HTSM

Roadmap Aeronautics 2020 - 2025

April 2020

Roadmap Update Team:
Peter Kortbeek (GKN Fokker & Chair HTSM Aeronautics Roadmap)
Arjan Vergouw, Louis Aartman (LRN)
Jeffrey Zitter (NLR)
Ingrid Houthuysen, Joris Melkert (TUD)
Frank Jansen (NAG)

CONTENT

1. PROLOGUE

During the process of updating the Aeronautics Roadmap in the first quarter of 2020, the corona virus heavily affected the worldwide society. Many countries took severe countermeasures in order to stop or slow down the spread of the virus, such as lockdowns. All sectors are affected and at this moment it is still unclear how long the crisis will last. In any case, the economy sees a serious downturn and many large and small companies are at stake and have gone into a survival mode. The aeronautics sector sees a strong reduction in the number of flights and large parts of the aircraft fleet are grounded. Many airlines now need substantial governmental support to survive. Without passengers and cargo, not only the airlines but the whole sector is affected. The current scenarios predict a much larger impact of the corona crisis compared to previous events, such as 9/11, SARS and MERS, which in retro perspective have proven to be small ruptures in the growth curve. Whereas Figure 2 in the next chapter shows a sustainable growth, the scenario in the figure below is one of deep recession, followed by a rather slow recovery. The expectation is that the recovery will take at least a couple of years and effects may differ locally. In addition, the long distance traveling will recover more slowly than the market for short and intermediate distance journeys.

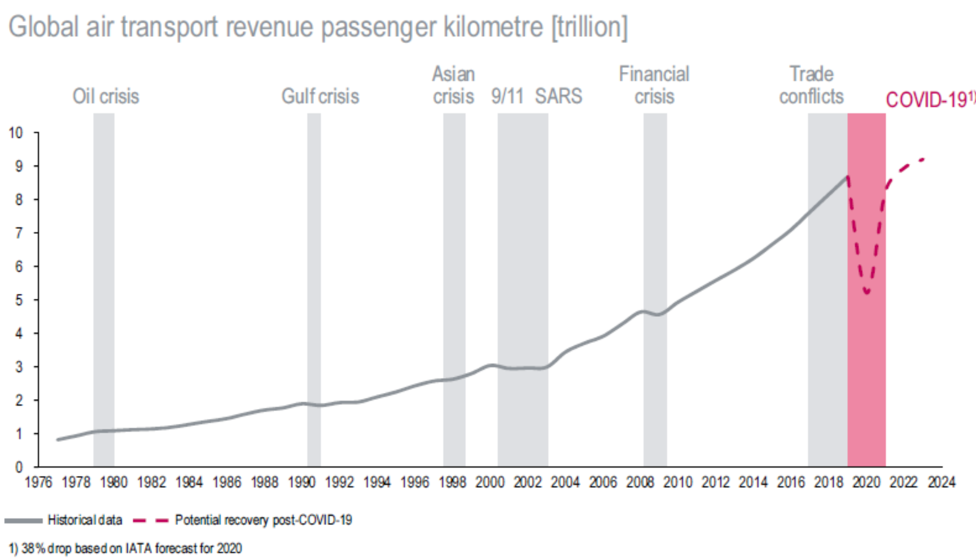

Figure 1 Air transport has proved its resilience over the past 50 years, and is expected to recover again following the COVID-19 crisis (source: Boeing, Roland Berger)

The crisis of course will certainly have an effect on the outlook presented in this Aeronautics Roadmap 2020 2025. With many companies and institutes in the survival mode, the budget available for R&T in the coming years will most likely be significant less than anticipated before the crisis.

However, the strategic direction in the Roadmap is on sustainable aviation and safety. Even if the number of passenger-kilometres would stay for years on the level of 2010 or even below, climate neutral aviation is still the strategic direction. In this respect, the roadmap is robust. It can well be argued that investing now in sustainable aviation, will lead to a better starting position of the Dutch stakeholders after the crisis. The current situation could even buy some extra time to realize the much needed developments. But this requires an expeditious approach of the situation. Postponing investments will cause unnecessary delays and would create a bigger gap between the Dutch businesses and their foreign customers and competitors. Expeditious acting now also secures the continuity of the excellent capabilities and know-how that the Netherlands aeronautics sector has built up during the past one hundred years.

2. SOCIETAL CHALLENGES AND ECONOMIC RELEVANCE

Aviation is recognised as one of the top advanced technology sectors in Europe and generates innovation that benefits society at large. The sector includes airframe and system components development and manufacturing, Maintenance Repair and Overhaul (MRO), Research and Development (R&D) as well as the suppliers of systems for the ground-based segment. The Dutch aviation sector has an annual turnover of approximately €5 billion. The sector focuses primarily on the development and supply of high-quality components and software applications and is specialized in aircraft manufacturing and in maintenance of aircraft. The sector provides high-level employment. The Dutch aviation sector is embedded in the international (Europe and beyond) supply chain.

However, with an anticipated continuous growth in demand for air transport until 2050 and beyond it is essential that travel not only remains safe, secure, fast and affordable but also becomes climate neutral. This also pertains to affordable and sustainable production and maintenance.

Societal challenges

The Advisory Council for Aviation Research and Innovation in Europe (ACARE) has set challenging goals in their document "Flightpath 2050"[1]. Research and innovation in aviation is the key to tomorrow's mobility and prosperity as well as environmental and energy challenges. Five key challenges have been defined:

1. Protecting the environment and the energy supply

The original aim of Flightpath 2050 was to reduce CO_2 by 75%, NO_x by 90% and noise by 65% (all relative to the year 2000 and all at TRL6 level of maturity). However, with the instalment of the European Green Deal the ambition has increased. By 2050 aviation should be climate neutral.
Even lighter aircraft, new and more fuel efficient propulsion concepts, more efficient aerodynamics and new systems are needed. Circular design will be required. Focus has to be on the development of "green" technologies and products, including the use of biofuels and even more, synthetic fuels. In addition to that improved operations like the full implementation of the Single European Sky are key in achieving the goals.

2. Ensuring safety and (cyber) security

While aircraft safety depends to a large extent on the further minimization of human errors, new aircraft systems and materials will further improve the safety of air transport. Cyber security is also a topic of growing importance. The primary function of military aviation is to play a role in the security of the population, locally and globally. Research into the integration of sensors in aircraft will improve peace keeping operations.

3. Maintaining and extending industrial leadership

Target setting by ACARE is not only done to meet the societal challenges, but also to strengthen industrial competitiveness and extend leadership. Competition comes from established players but also from emerging challengers that receive significant amounts of national support. Substantial investment is required in innovation, research and technology with the appropriate, strong, positive supporting policies.

4. Prioritising research, testing capabilities & education

The aeronautics sector is characterised by high demands on research and innovation and a long time-to-market (5 to 7 years) and breakeven period (15 to 20 years). Decisions on research and technology development may have consequences on the future of the sector decades after they have been made. The aeronautics sector must therefore be supported by public and private world class capabilities and facilities in research, development, test

[1] Flightpath 2050 - Europe's Vision for Aviation, report of the High Level Group on Aviation Research

and validation. It should provide a top-level education to the current and future employees of the aeronautics sector that is adapted to its needs.

5. Meeting societal and market needs

In 2050 passengers, freight forwarders and shippers must be the clear focus of the transport sector in which aviation is a key player, which requires a paradigm shift from a perspective centred on the operators to a perspective in which the customer comes first.

Given the urgency to move towards climate-neutral aviation it is important that developments get accelerated. In aviation the development cycles are very long as well as the time to market. Therefore, we need to become more disruptive now to make real changes. In that sense the period until 2050 gives us the time to make two major steps. The first step is to develop and certify aircraft that are 30% more fuel efficient and can be introduced by 2035. This is a large technical challenge and will require significant improvements in all parts of the aircraft: better aerodynamics, light weight structures and more fuel-efficient engines. In addition to that, existing aircraft have to be retrofitted such that they are capable of using sustainable aviation fuels like bio kerosene and synthetic kerosene.

The second line of development will lead to a more disruptive step. This development has to start in parallel with the first step. There we need to make the step towards climate neutrality. This will require disruptive propulsion and aerodynamics concepts. This will also require large scale deployment of sustainable aviation fuels and/or in combination with electric propulsion that will be combined with next gen airframe and systems technologies requiring less energy to be propelled – less weight and less drag. Introduction into service should take place before 2050 to still have a significant impact on the climate impact of the fleet.

Market size

In line with the growing demand for air transport, the global demand for new civil aircraft will grow at an average yearly rate of 4.4% - 4.7% (20 year world annual traffic growth, see also Figure 2). Airbus and Boeing forecast a global market demand for about 34,150 to 39,210 new aircraft (large civil aircraft with 100 passengers and more, excluding freighters) by 2038. The global turnover represented by these new civil aircraft represents a value of US$ 5-6 trillion. The fleet growth will also drive the size of the MRO business, which Airbus expects to double, from US$60 billion to more than US$120 billion a year by 2038. Although the market is very sensitive to disruptions on the local and global scale, history has shown that in the long run the market is very resilient to these disruptions.

The long term impact of corona will even create more pressure on affordability and time to market of new technologies. On these topics, the Dutch aeronautics sector can make a difference if we get the right funding and support to be a dependable partner for development and production.

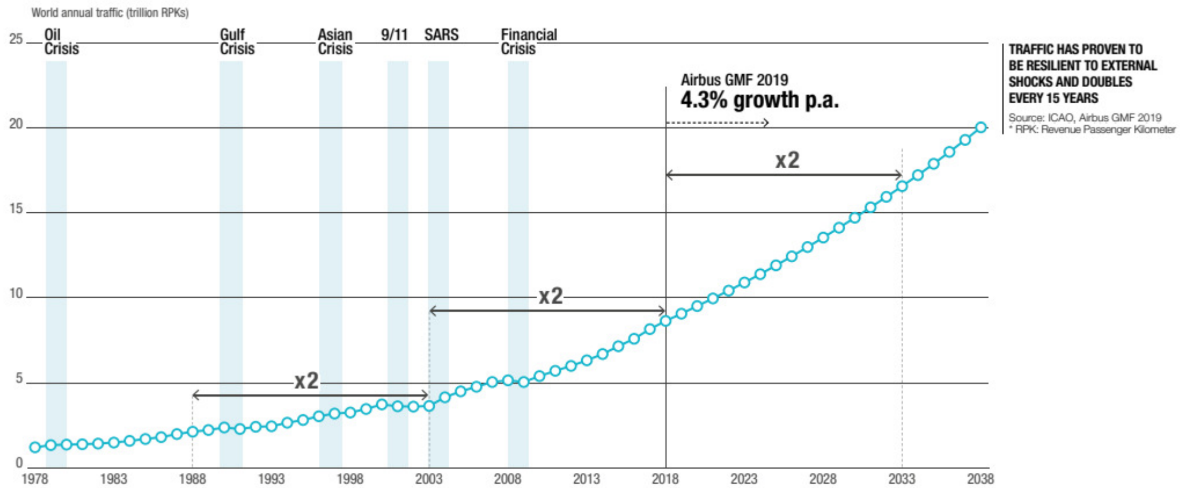

Figure 2 Airbus GMF predicting long term demand (source: ICAO, Airbus GMF 2019)

Competitive position of Dutch ecosystem

The Netherlands is recognized around the world for its knowledge-driven products, services and concepts and its skilled workers. The Netherlands is attractive for excellent connectivity to the rest of the world and its high level of education. The Netherlands offers excellent business and industrialization conditions for domestic and foreign technology companies and is an attractive place to live and work for aeronautics entrepreneurs, researchers and students. The continued support of national and regional government is key for this success. The ambitions of the Dutch aeronautics sector are to double its market share by:

(i) achieving global market leadership in aerospace materials,
(ii) participating in new aircraft platforms, with special attention to emerging economies,
(iii) delivering complete systems and integrated products and services,
(iv) reaching an international leading position in the worldwide maintenance market through revolutionary maintenance concepts,
(v) have the best education in aeronautics.

To meet this ambition the sector needs to be competitive at a global level. This can only be reached through education, research and the development of new technologies. The long business cycles (business for generations) lead to a need for the sector of credit facilities (revolving, long payback time), demonstration projects and a dedicated aeronautics programming.

3. APPLICATIONS AND TECHNOLOGIES

State of the art for industry and science

The Dutch aeronautics sector operates in market niches and its competitive position is based on advanced knowledge and innovative technology development. In 2018 a number of key technologies have been identified that are needed for these developments.[2] The key technologies that are directly relevant for the aeronautics sector are advanced materials, advanced manufacturing systems and processes, and measurement and detection technology. The key technology ICT is also very important as it allows the aeronautics sector to automate and digitise processes to work faster and cheaper on better products. Niche positions lead to five well-defined technology and innovation themes for the aeronautics sector that fit in the key technologies identified above.

1. **Aerostructures**: The Dutch aeronautics sector has a strong position on tail sections, wing boxes, movable wing parts, landing gears and other structural parts. It has excellent capabilities in designing and manufacturing composite and fibre metal laminate components and structures and has a solid reputation as global supplier of advanced materials and coatings.
2. **Propulsion and power, systems and components**: Strong industrial position on subassemblies for high pressure compressors, Auxiliary Power Units (APUs) and parts (blisks, impellers, casings, seals, shrouds, turbine blades, and engine starters). The knowledge infrastructure offers key know-how on the aircraft and the powerplant integration and offers therefore optimization opportunities.
3. **Maintenance Repair and Overhaul**: The outstanding Dutch MRO activities are ranging from overhaul of aero engines to composite repair, new concepts to reduce life cycle costs, corrosion, (prognostic) health monitoring from components and systems up to complete aircraft, utility and VIP conversion activities.
4. **Aircraft systems**: The sector has an excellent position on aircraft interconnection systems and aircraft interior systems.
5. **Future concepts**: Next generation (self-healing, multifunctional) materials including novel manufacturing processes, new aircraft integration and certification (thanks to Fokker heritage in aircraft manufacturing, presence of DNW and many second tier suppliers with a worldwide customer base) and new applications such as drones, Urban Air Mobility (UAM), personal air vehicles, eVTOL and (hybrid-)electric aircraft are key areas for Dutch industry, academia and research institutes.

The key technology and innovation themes will be supported by:

- **Enabling Technologies**: Not only “aerospace” technologies are needed for innovation within aeronautics, other technologies become more and more important for aeronautics. This can be technologies used within an aircraft, (AI, hydrogen, etc.) but also technologies that are needed for manufacturing and maintenance (robotising, design tools, etc.) or at the airport (block chain). Since aeronautics has very high safety requirement, these technologies have to adapted and integrated in the aeronautics processes. Also measurement of climate impact is considered to be enabling technology.
- **Airport infrastructure and systems**: With showcase example 'Amsterdam Schiphol Airport, the Netherlands has built an asset of high economic value in the last century. The many innovations were developed by Dutch suppliers and experts. Current trends are focused on passenger experience and smarter handling of processes within an airport with more efficiency and reduced energy consumption.

The Dutch position in aeronautics is often a direct result of intense collaboration between the Dutch knowledge infrastructure (universities and research institutes), which generates innovative concepts, offers state-of-the-art

[2] ‘Quantitative Analysis of Dutch Research and Innovation in Key Technologies’ van Elsevier Research Intelligence (June 2018)

mathematical modelling and experimental testing of key behavioural aspects, and Dutch industrial companies taking validated technologies to industrial production. Such an intensive collaboration is unique in the world and it enables the Dutch aeronautics sector to compete globally. Again, the support by national and regional government is key for this success.

Developments in present and future markets and societal themes

Collaboration within the five technology and innovation themes offers many opportunities for successful research (fundamental and applied) that leads to new applications and industrial productivity. New technologies and applications also open the sector for new entrants, e.g. start-ups and parties from other sectors. Examples are (hybrid) electrical propulsion systems, storage of alternative fuels and conversion systems like fuel cells.
The following table shows the link between the societal challenges, developments in present and future markets and the technology and innovation themes.

Lucht- en Ruimtevaart Nederland

Table 1 Link between themes, developments in present and future markets and technology and innovation themes

Societal theme	Subagenda	Developments in future markets	Technology & innovation themes	NL strenghts 2020 - 2025	MMIP / MJP
Energy transition & sustainability	Integral Knowledge & Innovation Agenda / Future-proof mobility systems	Reduction of CO2, NOx and noise / Sustainable aviation	Aerostructures Propulsion and power, systems and components Aircraft systems Future concepts Enabling technologies Airport infrastructure and systems	*Smart, multifunctional, light materials and structures*	*IKIA* MMIP 6: Sluiting van industriële kringlopen MMIP 9: Innovatieve aandrijving en gebruik van duurzame energiedragers voor mobiliteit MMIP 10: Doelmatige vervoersbewegingen voor mensen en goederen *Deel-KIA Toekomstbestendige mobiliteitssystemen* MMIP: Toekomstbestendige mobiliteitssystemen *KIA Veiligheid* MMIP 6.1: Toepassing van robots/autonome systemen/drones (RAS/RPAS) MMIP 6.2: 3D-printen voor onderdelen, lokale bouw en materiaalontwikkeling MMIP 6.3: Energiesystemen & circulariteit *MJP* 27 Composiet 32 Materials innovations (Brightlands MC) 34 Smart Industry 38 Batteries of the future 41 Duurzame Luchtvaart, Ontwikkeling Hybride Elektrisch Vliegen 73 Soft Advanced Materials (SAM) 82 Materiaaltechnologie - made in Holland
				• Composites, including thermoplastics and FML	
				• New resins	
				• Metals for additive manufacturing	
				• Self-healing materials	
				Sustainable manufacturing	
				• Design for manufacturing	
				• Digitalization and automation of manufacturing processes	
				• Advanced manufacturing of complex composite (thermoplastic) and metal (3D-printed) parts	
				• Virtual testing	
				More efficient and quieter aircraft	
				• Novel aircraft configurations	
				• (Hybrid-)electric aircraft, drones, UAVs, personalized air mobility	
				• New propulsion concepts	
				• Alternative fuel sources	
				• Innovative smart wing and empennage	
				• Interior/airframe integration	
				• High temperature engine components, blisks & seals	
				• In-flight in-situ acoustic absorption	
				• Aero-acoustics	
				More efficient and quieter operations	
				• Advanced planning	
				• Fixed navigation routes	
				• Advanced air traffic management	
		Smart & safe aviation	Aerostructures Aircraft systems Future concepts Enabling technologies Airport infrastructure and systems	• Urban Air Mobility	
				• Novel automation, intelligent flight control systems	
				• Sensoring & sensors	
				• New wiring concepts	
				• Innovative cabin layouts and systems	
				• (Virtual) certification and qualification	
				• Very low level ops/urban airspace	
				• Inflight connectivity	
				• Drones & UAVs for observation and search & rescue	
				• Drone threat mitigation	
		Toxity	Aerostructures	• Cr-free coatings (REACH compliancy)	
	Circular economy	MRO, reuse, recycle	Aerostructures MRO Enabling technologies	• Design for maintenance, repair, overhaul, reuse and recycling	*KIA Circulaire economie* MMIP1: Ontwerp voor circulariteit MMIP2: Circulaire grondstofketens en processen *MJP* 27 Composiet 32 Materials innovations (Brightlands MC) 34 Smart Industry 73 Soft Advanced Materials (SAM) 82 Materiaaltechnologie - made in Holland
				• Maintenance optimization software	
				• Component maintenance and pools supported by innovative business concepts	
				• Smart end-of-life management	
				• Structural Health Monitoring (SHM) & Prognostic Health Monitoring (PHM)	
				• Advanced repair technologies for composites and metal	
				• Non-destructive inspection technologies	
				• Composites recycling processes (thermoplastic and thermoset)	
				• PMA parts	
Security		Social security	Aircraft systems Enabling technologies	• Remotely Piloted Aircraft Systems (RPAS)	*KIA Veiligheid* MMIP 4.2: Bevorderen ontwikkeling cybercompetenties MMIP 4.3: Defensieve cybertechnologie *MJP* 55 Cybersecurity – Digitale Veiligheid en Privacy
				• Military transport systems	
				• Cybersecurity	
				• Drone counter measures	

4. PRIORITIES AND IMPLEMENTATION

ACARE has developed an ambitious Strategic Research and Innovation Agenda (SRIA) for Europe to meet challenging goals set by Flightpath 2050. This includes already on-going programmes and projects, for which funding has been secured, as well as new ones, for which funding must be found.
Also, within the Netherlands Agreements have been drafted with all aviation stakeholders to accelerate the transition into a more Sustainable and finally climate neutral or emission free aviation in 2070. Several initiatives like the Action Programme Hybrid Electric Aviation in which roadmaps are being developed until 2070 are driving our priorities more towards sustainable technologies and in particular to engine (sub)systems using alternative energy instead of burning fossil fuels, hybrid/electric propulsion in combination with further optimization of aerostructures in terms of weight and aerodynamics.
Much more focus on accelerating the necessary innovations is required to deliver certifiable technologies on higher TRL levels on the short and mid-term. Given the fact that the "real silver bullet" has not been identified yet, we also have to put emphasis on long-term exploratory research to come up with new solutions in the prioritized themes, in particular on hybrid/electric propulsion related technologies such as hydrogen tank technology, fuel cells, electric storage systems and electromotor technology.
Priorities are set towards 2025 by the stakeholders of the roadmap for each of the five technology and innovation themes described in the previous chapter.

Technology and innovation themes – priorities

TI theme: Aerostructures

Subtheme	Research Topics	Priorities
Manufacturing	Bonding technologies	New assembly and joining technologies
	Non Destructive Inspection	Next generation Non Destructive Testing (NDT) technologies / smart and automated quality assurance for manufacturing
Materials	Coatings	Environmentally friendly materials / next generation coatings for high tech materials / corrosion and erosion resistant coatings, easy to clean / functional coatings, optimized coating inspection technologies
	Composites	New composite materials / effect of (automated and digital) manufacturing processes on mechanical performance of composites / thermoplastics / next generation FML / heat resistant composites like Ceramic Matrix Composites (CMC)
	Materials life cycle	State-of-the-art and future material development, production, testing, qualification, certification, sustainment, recycling
	Metals, ceramics	Additive Manufacturing / new alloys for direct manufacturing
	Multi-functional materials	Multifunctional / 3D printed / cost efficient high performance / hybrid materials / next generation FML / high temperature composites
		Re-usable and heat conducting plastics
Product and process development	Future aircraft structure	Patchwork aircraft structure, bionic design, optimized load paths, sound-fire-impact resistant structure, integrated structures for fast rotorcraft (compound helicopter, tilt rotor), morphing structures, sensors
	Structures design, smart structures and systems	Integration of structures and wiring / cost modelling / aircraft loads estimation and composites allowables
System engineering	(Prognostic) health monitoring	Structural health monitoring / Landing gear noise (flaps)

TI theme: Propulsion and power, systems and components

Subtheme	Research Topics	Priorities
Manufacturing	Composites	Manufacturing of composite parts / Coating application methods
	New manufacturing technologies	Application technologies / additive manufacturing / advanced manufacturing technologies for complex parts / automation and digitization / Shaping and joining high temperature metals
Materials	High Temperature Materials	Environmental impact on high temperature materials / advanced high temperature resistant materials and coatings
New aircraft	Electric Storage System technology	Hydrogen engines or fuel cells for drones
Product and process development	Design methods & tools	Design for manufacturing technology / design and development of engine assemblies / design knowledge for improved gas turbine cycles
	Electrical Motor technology	Cryogenic electrical machines / motors / drive for electric propulsion
	Engine subsystems	Gas turbine combustion systems / powerplant integration / (hybrid-)electric systems / electric power trains\
	High Temperature Materials	Components (with exotic metals - turbo generator) for high temperature applications / double flow ducts / tubing heat exchangers
	Hydrogen tank technology	Composite hydrogen storage technology under 350-700 bar pressure / associated certification requirements for on-board aircraft usage
	Propulsor technology	Future propulsors like distortion tolerant fans and propellers
System engineering	(Prognostic) health monitoring	Prognostics and health management of gas turbine components (incl. life assessment, sensors)
	Electrical Distribution System technologies	Battery energy management systems and software

TI theme: Maintenance Repair and Overhaul (MRO)

Subtheme	Research Topics	Priorities
Manufacturing	Corrosion	Anti-corrosion, surface treatments, mobile diagnostic equipment / effect of fungus on structural performance
	Repair	Composite repair, determination design airworthiness strategy, damage tolerance / 3D printing and repair (3D printing for repair and repair for 3D printing) / repair of hybrid (metal/composite) structures
Product and process development	(Prognostic) health monitoring	Further automation NDI inspection methods / in-service damage assessment, SHM / predictive maintenance simulation / condition based maintenance / big data applications / software to predict and optimise maintenance
	Re-engineering, PMA parts, retrofitting	Improved product & process development
Systems engineering	Systems for green aircraft	Modification / retrofit existing systems / aircraft with new technologies
Advanced inspection	AI image analysis	Artificial Intelligence can support the image analysis in order to detect anomalies e.g. main blades, AIIR Innovations.
	Advanced sensors	New innovative sensors with advanced features, such as topological scanning
	New inspection tools	Drones enabling remote inspection under all weather conditions

TI theme: Aircraft systems

Subtheme	Research Topics	Priorities
Product and process development	Systems for green aircraft	Modular systems (avionics, electro-mechanic actuators, electric driven subsystems for pressurization, cooling etc.) / Environmental Control Systems (ECS), integrated wiring systems / antenna systems / control systems / training and simulation systems / user experience
	Systems for safe aircraft	Communication, navigation and surveillance (CNS) systems / sensor systems (radar, optic, acoustic) / display systems / protection systems / flight management systems / user experience

Subtheme	Research Topics	Priorities
System engineering	System design methods and tools	Airworthiness rule making / smart system certification / instrumentation systems / model based design, software and simulation technologies / connectivity solutions

TI theme: Future concepts

Subtheme	Research Topics	Priorities
Aircraft in a new environment	Systems for safe aircraft	Autonomous / Remote Controlled flight
Materials	Bio-inspired materials	Bio inspired, self-growing, self-healing materials
New aircraft	Electric Storage System technology	Future hybrid / electrical aircraft concepts must be able to handle battery packs with 10-20 x more energy density compared to 2014
	Future cockpit	Integral safety assessment of cockpit and ATM in integrated air-ground-space system-human machine interface, future cockpit and control concepts, human factors & resilience of future complex systems (incl. cockpits), connected cockpit, training and simulation
	Integral life-cycle cost	Technology development constrained by life-cycle cost
	Systems for green aircraft	Gradual increasing degree of hybridisation on mainstream aircraft (like A320 and B737) and combine with incumbent propulsion
	Development new aircraft concepts	Future aircraft concepts, with distributed propulsion technology and concepts, multi-disciplinary engine-airframe integration, future aircraft design - certification - validation methods, multidisciplinary optimization of aspect ratio 10-15 wing, future concepts for passenger cabin, (active) noise reduction technologies, different aerodynamics, laminar wing, user experience, windowless aircraft, alternative energy sources
Product and process development	Future aircraft systems	Remotely Piloted Aircraft Systems (RPAS), impact more electric on systems, integrated systems for fast rotorcraft, cheap aircraft weight and balance system

TI theme: Enabling technologies

Subtheme	Research Topics	Priorities
Manufacturing	Fibre Placement Technology	Next generation fibre placement technologies / effects of defects
	Robotizing	Automated composite manufacturing technologies / faster & cheaper Resin Transfer Moulding / press forming / digitization
	Smart factory	Virtual manufacturing / innovative metal forming manufacturing technology / digital twin concepts for smart manufacturing units / automation and digitization
Product and process development	Design methods	Future intuitive analysis & design methods, certification requirements and interpretations, future production and assembly technologies, short turnaround time and low cost, multiscale simulation techniques, virtual integration
	Design methods & tools	Knowledge Based Engineering (KBE) / new certification and qualification philosophy (smart building block) / topology and shape optimization / virtual integration lab and virtual twin development / design for manufacturing technologies / performance assessment tools / design for repair
	Fuel cell pack technology	(Hydrogen) fuel cells
	Hydrogen tank technology	Development of technology to store hydrogen under cryogenic conditions in CFRP tanks
		Fire extinguishing en hydraulics
		Research in cryogene technologies
	Smart wind tunnel testing and sensor technology	Miniaturized remote controls of wind tunnel (WT) models, smart WT correction methods, aero-elastically scaled WT models, cost-reduction WT models, rapid prototyping of wind tunnel models with embedded sensors (3D printing), accurate balances with temperature compensation, sensors and HUMS validity for maintenance optimization

Subtheme	Research Topics	Priorities
Product and process development	Virtual testing	Mechanical testing process simulation / behaviour simulation
	Measurement methods	Climate impact like emissions (CO_2, water vapour, NO_x), noise
Systems engineering	Design methods & tools	Model based software development
	Electric Storage System technology	(Battery) energy management software
	Development of new baggage handling concepts and systems	Blockchain technology for new service concepts
	More autonomy	Autonomous vehicle technology (AGV) for airport services and operations

TI theme: Airport infrastructure and systems

Subtheme	Research Topics	Priorities
Aircraft in a new environment	Development of new ground systems, procedures and concepts	Remote Tower / ATC systems / flight procedures / very low level ops, concepts, procedures and supporting systems
Product and process development	Development of new ground systems, procedures and concepts	Electrical GSE at airports
	Development of new baggage handling concepts and systems	New generation of more sustainable and flexible baggage handling systems, new baggage handling concepts as “baggage as a service”
Remote inspection technologies	Accommodate (shared) airspace & relevant procedures on airports for RPAS/drone services	Drone services for outdoor aircraft inspections, runway and infrastructure inspections, bird control, emergency services (safety)

Implementation in public-private partnerships and ecosystems

The realization of the roadmap Aeronautics depends on the implementation mechanisms available for the so-called “triple helix”. Each development phase in the innovation cycle (from knowledge via technology to product development and industrialization) requires different approaches. College Lucht- en Ruimtevaart Nederland (LRN) plays a central role in the Dutch aeronautics sector involving industrial companies, SMEs, knowledge institutes and government. Different public-private partnership initiatives, both national and international, are part of the TKI programme according to the five technology and innovation themes. Under these themes, the different key technologies and their R&D&I needs have been and will be translated into collaborative research projects.

The Dutch aeronautics sector also looks beyond national borders and is heavily involved in international cooperation at five levels: (i) strategic alliances, (ii) international sharing of facilities, (iii) transnational and international institutional cooperation, (iv) joint industry participation in international collaborative R&D programmes, and (v) participation in and through international professional societies.

In 2019 a Dutch Action Plan for Air Transport "Smart and Sustainable" has been released to achieve 35% less CO_2 emissions by 2030. There is a shared ambition among leading air transport businesses and knowledge centres in the Netherlands aviation ecosystem to become the smartest and most sustainable players in the global air transport sector. Innovative organisations are cooperating closely with other sectors and enterprise centres to achieve this ambition and to ensure international relevance, as the sector also serves international customers.

Radical fleet renewal is a major theme in this plan and addresses both initial incremental aircraft improvements as well as future radically new technologies and materials such as hybrid and electric propulsion. To enable Dutch industry to play an important role, it was necessary to draw up a specific research agenda beyond the existing step-by-step innovations to focus on the development and demonstration of radically new systems and concepts. LRN brings together the parties that can develop new materials, constructions and powertrains. Airlines will support the development of radically new aircraft concepts and, where possible, replace or modify their existing fleets.

The sector participates widely in EU programmes. The main value of participating in EU-projects is to develop excellent scientific knowledge for the benefit of Dutch society, cooperation with OEMs, a large international network and new commercial opportunities. To be able to realize its ambitions in the future, the aeronautics sector needs the Dutch government to actively pursue a ring fenced/dedicated budget for aviation under national and EU programmes due to the specificities of the sector, as well as governmental support for continuation of a best practice public private partnerships such as Joint Technology Initiative Clean Sky. Clean Sky is the largest European research programme developing innovative, cutting-edge technology aimed at reducing CO_2, NO_x emissions and noise levels produced by aircraft and contributes to strengthening European aero-industry collaboration, global leadership and competitiveness.

The Memorandum of Understanding (MoU) with Airbus is an additional tool to promote international cooperation. The Airbus MoU defines a joint research and technology programme of common interest with the objective to extend and increase the international business relations between parties involved. This aircraft MoU has been agreed between Airbus, Fokker and the Netherlands Aerospace Group (NAG), consisting of more than 100 Dutch aerospace companies and representing the entire Dutch aerospace sector (production, maintenance, education, engineering, R&D and science). The sector is looking for new MoUs with aircraft manufacturers.

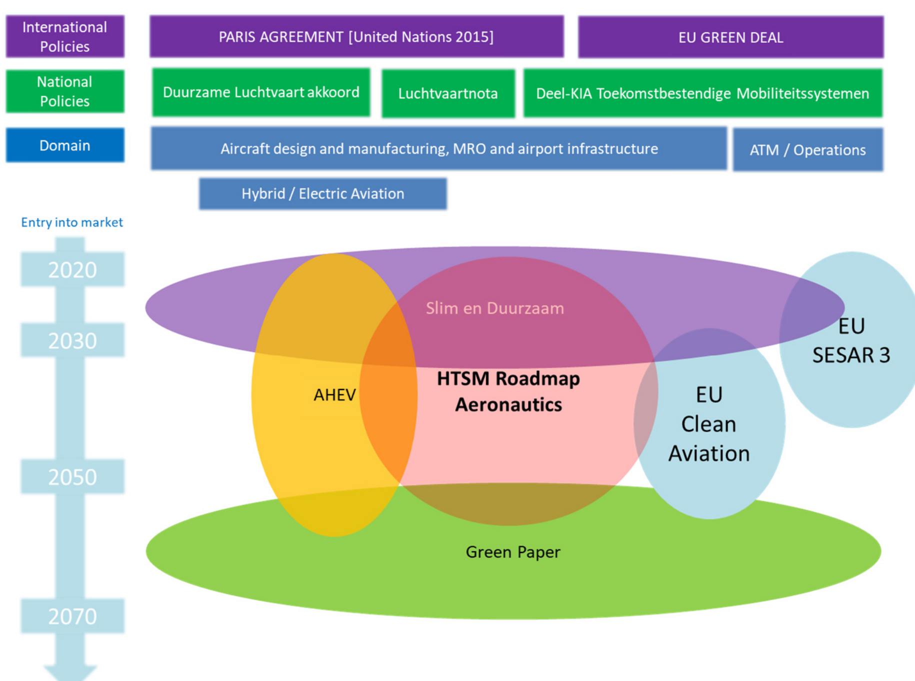

Figure 3 Overview vision documents

5. PARTNERS AND PROCESS

The Roadmap Aeronautics has been updated by a small group, consisting of partners from industry, universities, research institutes and aerospace organisations

Process followed in creating and maintaining this roadmap

In the past year many initiatives have been taken to prepare programs on sustainable aviation, like the Actieprogramma Hybride Elektrisch Vliegen (AHEV). College Lucht- en Ruimtevaart Nederland (LRN) is responsible for the highest level of coordination of this Roadmap. They represent the Dutch aeronautics sector. They also organised several sessions with the sector in order to get an overview of the relevant research and development topics of all partners in aviation, varying from small start-ups up to large companies and from fundamental research topics up to demonstration, certification and implementation. These overviews are used as input for the update of this roadmap. The updated version of the roadmap has been shared with many parties in aviation before finishing. SME's have been involved strongly in the creation of the overview and they were asked to review the Roadmap.

At European level the implementation of this Roadmap will be realised through collective R&D activities within European programs, covering all topics related to Flightpath 2050 targets, and directed towards a programmatic approach as defined in ACARE's Strategic Research Agenda. Representatives of the Dutch aeronautical sector play an active role in the aeronautics related bodies in the EU. With Airbus the Dutch sector is working on a renewal of the MoU. This MOU helps the Dutch sector by having a formal relationship with Airbus who is shadowing the developments and giving advise.

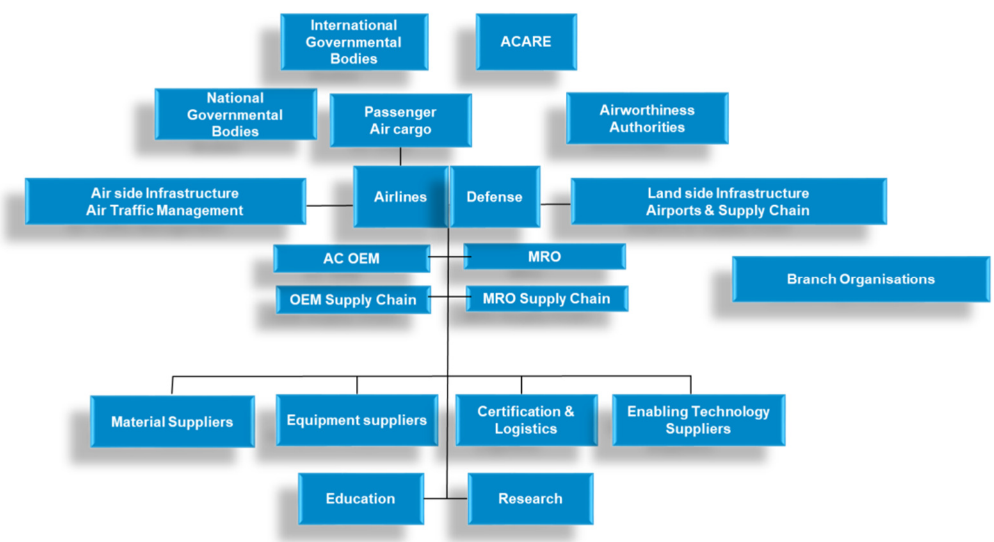

Figure 4 Aeronautics stakeholders

Partners in this roadmap

All partners from the triple helix are involved in this roadmap: partners from industries, scientific partners and regional and national governments. This roadmap has been created by partners from the aeronautical sector itself. For the execution, other partners will be needed. First to mention are the partners from the operational side, like the airliners and airports. Also cross sectoral partners will be involved, like other HTSM partners and science institutes like KNMI.

6. INVESTMENTS

Estimate for overall investment in R&D, as applicable to the roadmap (all figures are in M€ per year):

<table>
<tr><th>Roadmap</th><th>2020</th><th>2021</th><th>2022</th><th>2023</th><th>2024</th><th>2025</th></tr>
<tr><td>Industry</td><td>30</td><td>30</td><td>31.5</td><td>33</td><td>34.5</td><td>36</td></tr>
<tr><td>TNO</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>NLR</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td></tr>
<tr><td>NWO</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td></tr>
<tr><td>Universities</td><td>12</td><td>13</td><td>14</td><td>15</td><td>15</td><td>16</td></tr>
<tr><td>Departments (excluding TKI)</td><td rowspan="2">2.5</td><td rowspan="2">2.5</td><td rowspan="2">2.5</td><td rowspan="2">2.5</td><td rowspan="2">2.5</td><td rowspan="2">2.5</td></tr>
<tr><td>Regions</td></tr>
<tr><td>Grand total</td><td>52.5</td><td>53.5</td><td>56</td><td>58.5</td><td>60</td><td>62.5</td></tr>
</table>

European programmes within Roadmap	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Industry	10	11.5	13	14.5	15.5	16.5
TNO						
NLR	2	2	2	2	2	2
NWO	0.3	0.3	0.3	0.3	0.3	0.3
Universities	6	6	6	7	8	9
EZK-co-financing of EU-programmes	2	2	2	2	2	2
European Commission	8	9	10	11	12	13
Grand total	**28.3**	**30.8**	**33.3**	**36.8**	**39.8**	**42.8**

Lucht- en Ruimtevaart Nederland

APPENDIX A: STAKEHOLDERS

3D-Metal Forming
42 Solutions
AAR Aircraft Component Services
Aarding - CECO
Additive industries
Adecs Airinfra
ADSE
Aeronamic
Aerovantage
Air Liquide
Airborne
Airbus Defence and Space Netherlands B.V.
Aircraft Maintenance & Training School
AIS Europe
AkzoNobel
AmEuro Metals
Amsterdam Airport Area
Ansaldo Thomassen B.V.
ATS Applied Tech Systems
Avans Hogeschool
Avebe
AviaVox
Aviocom
Aviolanda Aerospace Woensdrecht
Avion Group
Belgraver
Bell Textron Supply Center B.V.
Benchmark Electronics
Boeing
Bond High Performance 3D technology BV
Brabant Development Agency (BOM)
Camfil B.V.
Cargill
Cimcool Industrial Products
Clear Flight Solutions
Collins Aerospace
Colson Europe
Custers Hydraulica
Daedalus Aviation Group
Deerns
Dejond
DNW (German-Dutch Wind Tunnels)
Dutch Thermoplastic Components (DTC)
Dutch-Shape
eezeetags
Egmond Plastic
Embraer Netherlands
EPCOR B.V.
FlowCut Waterjet Cutting
Fokker Technologies
GMT Benelux
Gogo Netherlands
Goudsmit Magnetic Supplies
Hauck Heat Treatment Eindhoven
Hogeschool Inholland Delft
Hogeschool van Amsterdam, Aviation
Holland-Controls B.V.
Johnson Matthey
Keonys
KLM Engineering & Maintenance
KLM N.V.
KMWE Aero Engine
KMWE Aerostructures
Kuehne + Nagel
KVE Composites Group
Landes High End Machining
Lelystad Airport
Logistiek Centrum Woensdrecht (LCW)
M.E.P.
Maastricht Maintenance Boulevard
Mainblades Inspections
MAN Energy Solutions
Marshall Aerospace Netherlands
MBO College Airport
MJB International BV
MovingDot
MTU Maintenance Lease Services
N.V. Nederlandse Gasunie
NACO, Netherlands Airport Consultants
NCIM Groep
NEDAERO
Neitraco Engineering
Netherlands Aircraft Company
NLR – Netherlands Aerospace Centre
Oerlikon Eldim (NL) B.V.
OPRA Turbines BV
Pekago Covering Technology
PM Aerotec
Pontus HeatTreatment BV
Possehl Aannemingsmaatschappij
PowerLinxx
Powerspex
Pronexos
Proponent
Qualitair Aviation Group
Rotterdam The Hague Innovation Airport (RHIA)
SABA Adhesives & Sealants
SACO Airport Equipment
Safran
SAMCO Aircraft Maintenance
Senior Aerospace Bosman
Siemens Industry Software
Sloecentrale B.V.
STORK
Straaltechniek International
Sulzer Rotating Equipment Services Venlo
Sun Test Systems
Surface Treatment Nederland
Tarkett
TCSH - Turbomachinery Control Services Habets
Technobis Fibre Technologies
Technology Park Ypenburg
TiaT Europe
TKH Airport Solutions
TNT Express
To70
Toray Advanced Composites
TTL group
TU Delft
Twente Airport
Uniper Benelux N.V.
Valmet Automation
Vanderlande
Vattenfall
VIRO
WFS PRO
Woodward Nederland B.V.
XYREC B.V.
Aircraft End-of-Life Solutions (AELS)
Aviall Services
Aviation Competence Centre
Chromalloy
EMS
IBM Nederland BV
Schiphol Real Estate
SII Netherlands
StandardAero Netherlands
Stratagem Group
UTC Aerospace Systems
VDL GL Precision
Zodiac Aerospace