A Preliminary Programme Outline
For Clean Sky 2

July 2012

A vital enabler for breakthrough innovations in Europe’s Aviation sector:
Securing the sustainable mobility of European citizens,
Minimising the impact on the environment,
Generating significant growth,
Creating high-value jobs
Disclaimer

This document reflects the current preliminary outline for a continued Aeronautical Joint Technology Initiative in Horizon 2020, as is currently being constructed and refined by the leading European Aeronautical industry companies, in collaboration with and through the Clean Sky Joint Undertaking. This document does not constitute a formal proposal and does not bind the collaborating participants to the programme outline, either in whole or in part. The document has been compiled for the sole purpose of aiding the European Commission in judging the merits of a continued JTI in Horizon 2020, and providing the industry’s consolidated view on required programme content and programme structure.
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0. Executive Summary

Clean Sky today is demonstrating the benefits of a true public private partnership. Based on the first five years of activity, the technical programme is on track and the participation of European stakeholders – particularly SMEs – is already higher than other FP7 instrument. Industry is increasingly using Clean Sky as the focus of their R&T programmes largely because of the flexibility in timing and the JU is a much more efficient management body relieving the EC of this burden.

A Clean Sky 2 will deliver vital full-scale in-flight demonstration of novel vehicle configurations. The advancement of the underlying technology at full systems level will form the building blocks for benchmark environmental and economic performance and bring crucial competitiveness benefits to European industry. This will enable the European Aviation Sector to satisfy society’s needs for sustainable, competitive mobility and high-value growth and employment.

Clean Sky 2 will be the key European instrument to overcome market failure and guarantee a sustainable advancement of aviation. This will help address the ‘valley of death’ between invention and innovation in the sector, where sustained high research investments are needed over long time periods at commercial risk, and the ultimate exploitation via capital investment in equipage can be decades later.

Clean Sky 2 will engage the best talent and resources in Europe and will be jointly funded and governed by the European Commission and the major European aeronautics industry companies. It will be endorsed and supported by the leading European aeronautic research establishments, and academic faculties. Small and medium-size enterprise and innovative sub-sector leaders will help shape promising new supply chains. Airlines (operators) and airport partners and associations will be seamlessly integrated in downstream research and innovation.

By pursuing joint European research on integrated new breakthrough innovations and demonstrating new vehicle configurations in flight, the program will provide the proving grounds for new concepts that would otherwise be beyond the manageable risk of the private sector. It will give the necessary funding certainty and stability to the Aviation sector and investors to develop and introduce game-changing innovations in timeframes otherwise unachievable, and create an ‘Innovation Urgency’. In doing so, Clean Sky 2 will significantly contribute to the Innovation Union, create high-skilled jobs, increase transport efficiency, sustain economic prosperity and drive environmental improvements worldwide: reinforcing Europe’s role leading the fight against Climate Change by positively contributing to lower emissions through technological advancement whilst enabling mobility to be sustained.

The programme is estimated to require a total public and private investment of approximately €3.6 bn and will run for the full duration of Horizon 2020. It is assumed that the programme will be supported by the European Commission in the form of a continued Public-Private-Partnership (PPP) wherein public and private Members will each contribute 50% of the required investment through contributions as customary in the Framework Programme.
1. Introduction

This document represents the proposal from the leading European Aeronautical Industry companies for a continuation of the Clean Sky aeronautics Joint Technology Initiative (JTI) within the Horizon 2020 Framework Programme. The aim of this continued public-private partnership, hereinafter referred to as Clean Sky 2, will be to build on the programmatic content and achievements to date, account for the significant product and market developments since 2007, and to take further decisive and innovative steps towards a sustainable and competitive European Aviation Sector: protecting the environment, serving European citizens’ needs and providing important growth and employment opportunity.

1.1 The strategic and EU policy context

The European Commission’s Transport White Paper of March 2011 spelled out clear challenges for the public and private sector actors in delivering ‘A Vision for a Competitive and Sustainable Transport System’. Among these were several with a significant bearing on the air transport system, and from which a concrete agenda for the sector has emerged:

- The need to use less and cleaner energy, and reduce negative impacts on the environment and key natural assets like water, land and ecosystems. The challenge was set to break transport’s dependence on fossil fuels “... without sacrificing efficiency and compromising mobility.”
- Technological innovation is recognized as “... essential in achieving a faster and cheaper transition to a more efficient and sustainable European transport system.” A transport research and innovation policy is recognized as a pre-requisite to the coherent development and deployment of the key technologies needed. Technology research should be complemented with a system-level and integration focused approach involving large demonstration projects to encourage market take-up.
- As a consequence the Commission has committed to devising “... an innovation and deployment strategy for transport, identifying appropriate governance and financing instruments, in order to ensure a rapid deployment of research results.”

As recognised in the White Paper, and elaborated in the subsequent Flightpath 2050 document, Aviation is inherently global, and is a vital sector of our society and its economy. Improving the efficiency of aircraft and traffic management operations is an imperative: it will secure a competitive advantage on top of reducing emissions. The European Aeronautics sector, as provider of almost half of the total worldwide fleet is clearly of sovereign importance to the European Union and its Member States. It is a sector in which European public and private stakeholders provide world leadership. It helps to meet society’s needs by:

- Ensuring competitive mobility solutions for passengers, freight and public services
- Minimising aviation’s impact on the environment through key innovations in products and services
- Providing highly skilled jobs, generating significant economic growth and creating wealth
- Significantly contributing to the balance of trade and European competitiveness
- Supporting Europe’s knowledge economy through substantial R&D efforts and deep supply chains
1.2 The aeronautics and air transport sector drivers

Aviation still faces the challenges prevalent when Clean Sky was set up. Despite the general economic downturn, global demand in all aviation segments shows resilient growth, with global forecasts of up to 5% per annum, and even higher growth rates in the Middle East and Asia. This translates into a pressing demand for more efficient and advanced air vehicles. The sector’s drive towards sustainable development, as defined in the ATAG Goals\(^1\) requires further acceleration to mitigate the expected four to seven-fold global increase in traffic by 2050 compared to 2000.

At the same time the global financial and economic outlook has deteriorated significantly, making investment in technology far more difficult, and adding to the ever more challenging competitive business environment. The private sector is unable to fund ‘at-risk’ the required investment in research over the sector’s exceptionally long business cycle: exploitation of successful research activity often only begins two to three decades later, as such providing little or no appeal in terms of attracting capital. Deferring or reducing this investment irreparably damages the innovation needed for the next decisive steps in aircraft performance.

Continued long-term public-private investment has made the European Aeronautics industry globally competitive, allowing it to drive the innovation agenda in many areas, including environmental performance. But the new challenges identified in Flightpath 2050 highlight the need for more accelerated innovation and for more far-reaching solutions. A continuation of the existing Clean Sky JT1 will ensure new concepts are fully validated in order to accelerate the market adoption of step change solutions.

1.3 Meeting the Challenges set in Horizon 2020

The Horizon 2020 programme was launched by the European Commission on November 30th, 2011, and sets the scene for Research and Innovation in Europe towards 2020. It notes as one key Societal Challenge: smart, green and integrated transport. The aeronautical sector is a critical actor in reaching the goals set out in Horizon 2020, and a continued public-private partnership through Clean Sky 2 can deliver key outcomes:

- **Creating resource efficient transport that respects the environment.** Building on the achievements under FP7 (particularly within Clean Sky), aeronautical research and innovation in Horizon 2020 must finish the job of achieving the ACARE SRA goals as set for 2020. Roughly 75% will be achieved at the end of Clean Sky, with the JT1 fully meeting its original goals. Beyond this, new efforts are needed towards reaching the Flightpath 2050 goals of 75% of CO\(_2\) reduction, 90% NO\(_X\) and 65% noise reduction. Clean Sky 2 can facilitate the first important steps for the medium term (up to 2035) in order to achieve these goals.

- **Ensuring safe and seamless mobility.** Aviation provides invaluable time-efficient mobility. New concepts can aid the air transport system (ATS) in meeting evolving mobility needs of citizens: more efficient use of local airports, faster connections, and reduced congestion. The Clean Sky 2 focus on the ‘System Readiness Level’\(^2\) of vehicles will demonstrate the benefits of technology at ATS level.

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1. Air Transport Action Group, common goals for the sustainable development of aviation for 2050
- **Building industrial leadership in Europe.** *Clean Sky 2* will help protect highly skilled jobs in Europe. In addition to continued competition with ‘traditional’ aeronautics countries, Europe now faces strong competitors from ‘BRIC’ nations. *Clean Sky 2* will enable European industry to deliver the necessary innovations based on affordable and sustainable technologies. This will be supported by design tools and methods, programme and supply chain management, and certification processes that will shorten time-to-market, decrease non-recurring costs, reduce risk, and create the global leadership essential for a sustainable industrial base.

These objectives will require both near term system level solutions which can be implemented in the next generation of aircraft, and breakthrough innovations to address the longer term – up to 2030.

As technologies become more complex and inter-connected, validation through demonstration is essential to enable industry to justify investment in new products.

### 1.4 In the footsteps of the first *Clean Sky* Programme – a logical next step

*Clean Sky 2* will be a natural continuation to the progress achieved in *Clean Sky*. This has become more important to ensure the successful implementation of *Clean Sky* results following the significant changes to the aircraft market from conditions assumed in 2007.

This first *Clean Sky* Joint Technology Initiative will end upon completion of the 7th European Framework Programme (FP7). The projects included in this first, ground-breaking aeronautical JTI have very positive results – the potential for significant reductions in emissions, important noise reductions, and more efficient use of raw materials. Close alignment in time and in content between projects of *Clean Sky 2* to its predecessor will allow for a seamless transmission of technical progress.

The advancements within the first *Clean Sky* are applicable to the aircraft at major component and large systems level. The time is now ripe for taking the additional research step on their potential combination and into complete aircraft demonstrators comprising innovative configurations. In addition to the integrated technology demonstrators (ITD), *Clean Sky 2* will introduce further integrated demonstrations and simulations of several aircraft systems at the aircraft platform level. These unite newly developed systems and technologies allowing the technological progress to unfold its full impact. The technological improvements instilled through *Clean Sky 2* will underpin innovative advances in the next generation of aircraft through mastering the technologies and the risks in time to meet the next market window to replace the current fleet.

**Ensuring a continuation of the Aeronautical JTI with *Clean Sky 2* will enable Europe to:**

- Develop smart, environmentally friendly and energy efficient aircraft that operate worldwide and thereby meet environmental and societal targets for a more efficient, safer and environmentally friendly air transport.
- Achieve its strategic social priorities with sustainable growth, creation of wealth and stable employment in fields of high technology.
- Win global leadership for European aeronautics with a competitive supply chain, including academia, research and small and medium size enterprises.
2. The Clean Sky Joint Technology Initiative: Progress to Date

The concept of Joint Technology Initiatives (JTIs), now embedded in the existing Joint Undertakings (JUs) was established in the 7th European Framework Programme (FP7) in 2007. The Clean Sky JTI is the first 50/50 public private partnership in the field of aeronautics that is technically led by industry, with the active engagement of all stakeholders, and administered by a JU to ensure the needs of the wider public and society are addressed.

2.1 Recap of Clean Sky general features

The Clean Sky Joint Technology Initiative started in 2008, and constitutes an industry-wide, coherent programme totalling €1.6 bn, equally shared by the European Union and European Aeronautical Industry (including its extended supply chain). Targeting very significant environmental gains: 30% reduction in CO₂, at least 6 dB less perceived noise per operation and 60% less NOₓ emissions, it is de facto the operational arm of the ACARE platform in the field of environment. Clean Sky aims to mature and integrate technologies into system level architectures, such as (full) engines, electrical systems, structures, and innovative wings, and validate their viability through large scale demonstration, in flight or via suitable and representative ground testing programmes.

Clean Sky is split into 6 research areas, called “Integrated Technology Demonstrators” (ITDs), as illustrated below. Each ITD is led by two industrial companies. Beyond these twelve leaders, more than seventy “Associates” participate in the activities. Leaders and Associates are the Members of the Clean Sky Joint Undertaking, which is managed by an Executive Team of 24 staff.
The end date for the Joint Undertaking is currently determined by Statute as 2017: this demarcates the scope and sets the pace of the programme; for identifying the priorities, managing risk, and achieving the demonstration programme.

A very important innovation of *Clean Sky*, and potential asset for the aeronautical sector, is the Technology Evaluator: a separate and tailor-built project organisation with a state-of-the-art set of tools operated by the participants, among which are all major Aeronautical Research Organisations. This allows for a robust and independent assessment of the achievement of the Programme’s environmental objectives. It has raised the bar in terms of on-going monitoring of research impacts and has been noted within ACARE\(^3\) as an instrument with the potential to aid in monitoring a broad set of objectives such as set in the ACARE SRIA for 2050.

Up to 50% of the funding is available for the Leaders – who largely determine the design and integration of the demonstrators. 25% of the funding is for the Associates – selected through an open process before *Clean Sky* was created, with the remaining 25% (as a minimum) reserved for Partners, who are selected through periodic Calls for Proposals, for well-defined, focussed topics contributing to the demonstrations.

The Programme had a slow start in 2008-2009, because of its novelty and due in part to the size of such a PPP. Now it is up and running and is demonstrating important successes. The current progress can be summarized as follows.

### 2.2 Technical Progress

The demonstrators under development in *Clean Sky* are widely varied and of different sizes. Around 20 important demonstrators are foreseen, on ground or in flight, pending on what is technically necessary and on the *Clean Sky* timescale. In all cases, the first half of the Programme was dedicated to design, partial tests, start of manufacturing, and key programme gates such as Preliminary Design Reviews and Critical Design Reviews. In 2012, the two first demonstrators from the SAGE (Sustainable and Green Engines ITD), namely large engine and turboshaft engine will be ground-tested. These are currently under final preparation. The others will follow, with a majority of them achieved by 2015, and a small number in 2016.

Some technology development activities within *Clean Sky* are not targeting the highest maturity (i.e. TRL6) within the current timescales and budget. While many low TRL elements have been terminated through the down-selection processes in each ITD (as not appropriate or too far-reaching), some “lower-readiness level” technologies have been retained and are continued given their high potential. These technologies are clear candidates to be taken on board a *Clean Sky* 2 JTI for a full-scale, final demonstration, as part of the effort to achieve a new set of objectives.

The annual budget execution rate and the rate of achievement of milestones and deliverables are sufficiently close to the target to ensure all demonstrators are under control. Among the most important, we can highlight the Natural Laminar-Flow wing flight test (on an A340), the Open Rotor engine ground and flight test, the “Lean Burn” NOx-reduction combustion chamber run in a full-size engine, the electrical wing ice-protection systems, the environmental control system, the full scale composite structures (cockpit, wing

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\(^{3}\) ACARE Monitoring Group, 2012

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box, fuselage section) ground and flight tests, the Diesel rotorcraft, the active rotor blade, the eco-designed structures and advanced, green Flight Management System (FMS) functions. Pieces of hardware (or software) are now available in all these fields.

All activities are monitored on a quarterly basis and reported to the Governing Board by the Executive Team. This includes risk management at strategic level⁴.

Annual reviews are organized, as well as targeted reviews when necessary, with the participation of external experts – the majority of which are part of the Scientific and Technological Advisory Board: this allows this independent group to keep a global and current view of progress, best practices, common areas of improvements, and key interfaces.

### 2.3 Environmental objectives

The environmental objectives can be reached only when the demonstrators are run and confirm the readiness of the right technologies. In the meantime, the technologies are selected; laboratory tests and parts tests are performed, allowing an increasingly precise forecast of the expected results. Data concerning efficiency, fuel consumption, weight, aerodynamic performance, etc., are included in consistent “concept aircraft” which feature the selected technologies. This allows the Technology Evaluator (TE) to operate. The first assessment by the TE was performed at the end of 2011. While not all categories of aircraft and not all parameters are addressed yet, for technical reasons, this assessment has strongly confirmed that Clean Sky was on the right track with respect to these objectives. In particular, short/medium range commercial aircraft, as well as regional aircraft, could deliver up to 30% improvement in CO₂ emissions. New business jet designs could deliver a 2/3 reduction in noise affected areas during take-off. In 2012, this assessment is being updated and complemented for most of the missing areas, e.g. noise of short/medium range aircraft or rotorcraft.

This 30% level confirms that the Clean Sky technological programme is the major contributor to ACARE SRA targets for the environment which are: 50% reduction in CO₂, out of which 40% are expected from aircraft (vehicle) technologies and 10% from ATM and operations. The Clean Sky Programme’s key goal of delivering ‘up to 75% of the vehicle technology gains’⁵ required is thus fully being met.

In addition, this first assessment has also demonstrated the viability of the TE as a process and as a set of coordinated tools. The TE, as such, will be an output of Clean Sky, which has a strong potential for further use.

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⁴ On this matter, the most important risk today is linked to the Open Rotor flight test: the provision of a “flyable” engine, able to get the permit to fly (which means a series of dedicated tests for critical parts), with the right controls and the right instrumentation, is not covered by the Clean Sky funding (limited to the ground test).

⁵ Clean Sky Programme Proposal 2007
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2.4 Participation

Clean Sky should reach 50% execution of the technical programme during 2012, which corresponds with the mid-point of the full programme; this is a rough indicator that the projects, in average, are conforming to schedule.

The membership of Clean Sky has demonstrated strong stability so far. No member has withdrawn; some of them have decreased their participation, but the activities have been taken over by others with no significant impact on the projects. The technical and financial rules and management have allowed some flexibility where needed – this is essential for such a multi-year programme. For example, while the effort on one of the two Open Rotor projects was decreased, a new project was introduced end of 2011: the Lean Burn (SAGE 6) with a new demonstrator, which allows Clean Sky to address the NOx objective far better than initially planned.

Regarding the extended participation in the JTI, the 13th Call for Proposals was published on July 4th. This process is running efficiently, and has brought many partners to Clean Sky. In total, up to the Call 11, Clean Sky involves more than 450 participants (Leaders, Associates and Partners) from 24 Member States. These Calls are especially well suited to SMEs, due to the focussed definition of work and to the fact that candidates can apply individually, via a simplified process – or build a small consortium. Almost 40% of the budget for Partners has been allocated to SMEs. Through Clean Sky, many newcomers can both find an easier entry point into the European research area, and create new links with “big industry”. This is an important enabler for the strengthening and deepening of European Supply Chains.

Despite the “downstream research” nature of Clean Sky, academia is remarkably well represented. More than 80 academic institutions are engaged either as Associates or Partners. They are involved in computations, simulations, lab tests and other activities.

This high number of Partners induces risks for the ITD objectives – even if not all of them are involved in the biggest ‘mainstream’, critical demonstrators. These risks are tracked within the risk management efforts of each ITD, and at the JU level. So far, some delays have been experienced but no critical contingency has emerged.

2.5 The socio-economic impact of Clean Sky research priorities

The economic case for Clean Sky was made in 2006/7. The contents identified in the original proposal supported the industry view of the market at the time. The market circumstances have changed significantly, with a number of key product introduction windows shifting to the next decade as a consequence of the financial crisis, and the introduction of intermediate solutions in the market as stop-gap, using ‘mid-life updates’ of 2000 level technology aircraft.

Conversely, it is evident that the next major fleet technology insertion opportunities, whilst at least a decade later than foreseen in the preparation of Clean Sky, now need step-change performance capability more than before. This makes Clean Sky 2 all the more relevant and important to the continued and relentless pursuit of better performance and industry competitiveness.
2.6 **Clean Sky** leverage effect in European aeronautics research and innovation

The Clean Sky JTI is itself a demonstrator. It is successfully demonstrating the relevance of such an instrument, for integrated, high readiness technologies, connected to the market needs, having the full European aeronautical sector working together to common objectives. This is a new dimension of public-private partnerships with unprecedented efforts linking major actors of the European aeronautics industry and research establishments, SMEs and academia.

As **Clean Sky** is still at mid-stream, it is premature to measure impacts and returns based on market outcomes. But the evidence is clear in respect to the leverage effect that **Clean Sky** has achieved within European aeronautics research and innovation.

With **Clean Sky** as ‘flagship’, a significant number or topical research activities have spawned outside the Joint Undertaking, varying from national aeronautics programme projects to private-venture funded actions, further underlining the benefit of a programmatic approach with clear goals and metrics. In particular, the Clean Sky approach to monitoring progress through its Technology Evaluator has given rise to interest from several Member States and from within ACARE: and areas of potential synergies in measuring progress towards goals set in the SRIA are seen.
3. The Rationale and Case for Clean Sky 2

Clean Sky 2 ensures the continuation and builds upon outcomes of the Joint Technology Initiative concept established by the 7th European Framework Programme (FP7) in 2007 and successfully embodied in the Clean Sky JU. It is the best approach to safeguarding momentum towards reaching the goals set for research an innovation in aviation within the Horizon 2020 timeframe.

3.1 Beyond Clean Sky – the rationale for next steps as JTI

Clean Sky has consciously been set up to be closely aligned with the strategy of leading integrators, as this is the best way to secure innovation through market adoption. Depending on the technology readiness level reached at the end of Clean Sky, and on the results of the relevant demonstrator(s), a significant number of technologies will have achieved sufficient maturity to become available for inclusion in development activity for future aeronautical products. Others may need to be strengthened through a further step of maturation within a Research and Innovation environment. For a few of the most innovative and most promising technologies worked on in Clean Sky (1), the preparation of the associated demonstrators shows that a yet higher level of integration will be needed: e.g. to jointly flight test new engine and new wing and overall aircraft configuration concepts which will have been tested separately in the current Clean Sky programme. This next, big step: demonstration at a representative (near) full-scale level of complete vehicle architectures should give the required level of confidence to the market actors to invest in non-evolutionary innovation. Thus the highest potential technologies (with high integration risk) stemming from the current programme, and demonstrated on a ground or flying testbed at the system level in Clean Sky, can find their potential application through inclusion in highly integrated vehicle demonstrations in Clean Sky 2, dedicated to new overall vehicle architectures.

This next step will also allow the Clean Sky 2 Programme to explore the interactions between Clean Sky matured technologies and those matured outside Clean Sky but still paramount for aircraft integration. Further topical content appropriate for a programmatic, downstream approach will come from topics not addressed in Clean Sky (such as passenger related functionality, internal noise, flammability, anti-icing technologies), which have been investigated and matured in parallel to Clean Sky but would benefit strongly from the programme driven approach emulated in Clean Sky as JTI.

The aim in Clean Sky is to reach technology maturity, according to the Technology Readiness Level methodology\(^6\) of TRL5 or TRL6, meaning that either “a component will be validated” (TRL5) or “a system model or prototype will be demonstrated” (TRL6) in a relevant environment. This environment is either simulated on ground or created directly in flight when the individual system/component can be embodied on a test aircraft. A further tool to manage the effective synthesis of technology into viable innovations exists with the concept of System Readiness Level\(^7\) (SRL). Considering the aircraft as the upper level ‘system’, the vehicle ITDs in Clean Sky (SFWA, GRA, GRC) can be classified as “Technology Developments”, targeting to “reduce technology risks and determine appropriate set of technologies to integrate into a full system.”

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\(^6\) TRL Methodology as developed by NASA and adopted by Clean Sky, see ........................................

This level of integration / synthesis no longer suffices to address the emerging market challenges. In addition to the integrated technology demonstrators, *Clean Sky* 2 aims to develop integrated flight demonstrators integrating aircraft systems at the platform level. These integrated demonstrators will enable industry to commit to more radical new products with increased confidence in their market success. Without this, emerging competitors copying today’s products will erode the market potential for the next generation of European products.

In order to reduce further the risks before launching the development of the new products awaited for by the market, it is necessary to bridge the so called “valley of death” and take the additional research step of combining systems and components individually matured in *Clean Sky* into complete aircraft demonstrators constituting innovative vehicle configurations. In terms of System Readiness Level (SRL) for the aircraft system, this means conducting projects that enter the broad domain of “System Development & Demonstration” with the objective to identify and overcome any stumbling block or technical pitfall that may appear either in the combination of several new technologies at aircraft level or as an intrinsic weakness of an innovative vehicle architecture.

**Ensuring a continuation of the Aeronautical JTI with *Clean Sky* 2 will enable Europe to:**

- Develop innovative energy efficient aircraft that operate worldwide and meet environmental and societal targets for more efficient, safer and environmentally friendly air transport.
- Achieve its strategic social priorities with sustainable growth, creation of wealth and stable employment in fields of high technology.
- Win global leadership for European aeronautics with a competitive supply chain, including academia, research and small and medium size enterprises.

### 3.2 The economic context

On average, 12% of aeronautic sector revenues, representing almost €7 billion per year for civil aeronautics alone, are reinvested in Research and Development (R&D) and support around 20% of aerospace jobs. The European aeronautics sector is a vital contributor to society and economy. The industry accounts for approximately 3% of EU workforce, generates roughly €220 billion of the European GDP per year⁸, and contributes positively to the EU’s trade balance with over 60% of its products exported⁹.

Every Euro invested in aeronautics R&D creates an equivalent additional value in the economy every year thereafter.

- The aeronautics sector is a key contributor to the European economy and the EU’s balance of trade
- Continued growth in demand for air travel raises new environmental and socio-economic challenges
- Research and innovation is core to EU competitiveness and drives sustainable value creation

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⁸ Flightpath 2050, p. 4
⁹ Flightpath 2050, p.7; export figure refers to 2009
3.3 Meeting the ecologic and socio-economic requirements

Aviation is a vital enabler of our economy and society. The aviation market continues to grow significantly and the associated societal challenges persist. Air travel will remain essential to ensure EU’s economic growth, mobility, integration and cohesion. Air traffic is forecast to grow by 4% to 5% per year in the next decade leading to a near doubling of traffic by 2020. This poses environmental, societal and economic challenges that can only be tackled through an intense and sustained cooperation between public authorities, industry, research organisations and academia.

Following the Europe 2020 strategy and the new European Transport Policy a new vision Flightpath 2050 was prepared in 2011 with ambitious goals for a sustainable and competitive aviation sector (such as a 75% reduction in CO₂ emissions by 2050, a 90% reduction in NOₓ and 65% in perceived noise compared to 2000 levels, and 4 hour door-to-door journey for 90% of European travellers). Based on the Flightpath 2050 goals, a renewed Strategic Research and Innovation Agenda (SRIA) is currently nearing completion under the auspices of ACARE. Clean Sky 2 will be an important enabler towards these Goals.

Substantial emissions reduction and protection of Earth’s resources will require radically new aircraft technology inserted in new aircraft configurations. Evidence shows that conventional aircraft configurations are approaching intrinsic performance limits.

Technology is the root of Europe’s current success and will continue to be the major competitive differentiator. Breakthrough technology: developed, matured and validated as ready for market adoption, will be required to secure future competitive advantage. Key to this will be pan-European cooperation with all stakeholders. Aeronautical technologies are a catalyst for innovation and spill-over into other economic and technological sectors.

As both market potential and societal challenges have evolved and grown, the overall socio-economic and environmental benefits of Clean Sky 2 will go well beyond the impact of Clean Sky as foreseen and now being executed under FP7.

3.4 Mastering the extended European Research and Innovation chain

The Horizon 2020 period will be decisive for delivering the required innovations in the next generation of European aircraft. By maturing the current wave of new technologies towards potential for market adoption within the decade after 2020, research outcomes from Clean Sky 2 will be applicable to 75% of the world fleet needing replacement up to 2050, and Clean Sky 2 technology will be able to address aviation emissions totalling over 70% of the worldwide civil air fleet.

Mastering the extended European research and innovation value chain is a prerequisite to sustaining global competitiveness. The European Commission and the European aviation industry stakeholders recognize that over the past 5 years, Clean Sky has become the single most important instrument to address large aeronautical research topics of advanced maturity up to the demonstration of integrated complex systems,

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10 European Commission, DG Transport and Mobility,  
11 Based on the proportion of the short to medium range aircraft in the global that will need to be replaced. Data derived from the Airbus Global market Forecast 2011-2030
12 NASA ERA System Readiness Report ASDL, April 27 2011

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complementing the Air Traffic Management R&D in SESAR. The set-up as Public Private Partnership (PPP) has proven to be by far the most effective way to ensure that all relevant European stakeholders (research establishments as well as industry and SMEs) cooperate in developing and maturing the most promising key technologies towards full to enable future industrial application.

With Clean Sky 2 building upon the Clean Sky results it can uniquely engage and align all the stakeholders in the European value chain and facilitate technology integration, up to vehicle test beds. As the prime European aeronautic research instrument within Horizon 2020, Clean Sky 2 will trigger the required level of research investments from both public and private sector actors. Clean Sky 2 will permit the pooling and aligning of the required capacities and capabilities from across Europe so as to deliver the innovation and growth needed and thereby be a driving force for further investment beyond its proper scope.

3.5 The crucial importance of public-private partnership

Clean Sky 2 will give the necessary stability and stimulus to the aviation sector stakeholders for introducing game-changing innovations at a scale and in a timeframe otherwise unachievable. Clean Sky 2 will focus and allow the coordination of aviation stakeholders’ initiatives and investments at European scale. It will significantly contribute to the Europe 2020 Flagship Innovation Union, creating high-skilled jobs, increasing transport efficiency, sustaining economic prosperity and driving environmental improvements worldwide. Clean Sky 2 will reduce the high commercial risk that is associated to research activity in the aeronautics sector which is beyond the capacity of private industry alone. The Clean Sky 2 Public-Private Partnership can attract strong private investment on the pre-requisite that this is complemented with the same amount of public funding.

3.6 Technological innovation critical to the future of Aviation

Clean Sky 2 will deliver vital, large scale and full scale in-flight demonstrations required for novel vehicle configurations, as well as integration and optimisation of underlying technologies at full systems level. This means, for example, that the impact and interaction of newly developed engines and systems, such as the contra rotating open rotor (CROR) which are to be tested ‘standalone’ in Clean Sky can jointly be simulated and tested when integrated with new airframe structures in new configurations. These highly integrated demonstrations form the building blocks for breakthroughs in environmental and economic performance, delivering crucial competitiveness benefits for European aviation.

Clean Sky 2 will engage the best European resources of all relevant stakeholders. In the framework of a public-private partnership it will be funded and governed jointly by the European Commission by major European aeronautic companies with support of the value chain industries and the leading European aeronautic research establishments and academic faculties.

In “joining up” European research on highly integrated systems and whole vehicle configurations, Clean Sky 2 will enable a sustained high level of research investment over a long period of time.
Clean Sky 2 will have the following game-changing impacts on the Aviation sector:

- A critical and essential enabler to reach the ambitious goals for European sustainable growth and prosperity set out in the European Commission’s proposal for Horizon 2020.
- Demonstrating innovative technology application as the key route through which to satisfy the forecast worldwide expanding demand in air travel whilst achieving the necessary levels of protection of the environment and use of the Earth’s natural resources.
- Key means to begin transition from the ACARE Vision 2020 to the new emerging ACARE SRIA driven by the Flightpath 2050 objectives: delivering on the Vision 2020 targets and taking a first step towards the Flightpath 2050 goals.
  - Expected to demonstrate technologies that will ensure reductions of aircraft CO₂ and NOₓ emissions by 2020
  - Contribute to noise pollution reductions in line with the ACARE 2020 goals and as foreseen in Flightpath 2050.
  - Reduction in fuel consumption that these improvements bring will also reduce operating costs thus benefitting both airlines and passengers.
- Delivering the needed framework to maintain Europe’s competitive edge and therefore secure employment.
  - Maintaining a strong industrial footprint within the EU and allowing European aeronautics remaining competitive.
  - Facing ever-increasing competition from established global competitors, and from new strong challengers in emerging economies.
  - Developing affordable and sustainable aviation technologies aiming to shorten the time-to-market, reduce risks, and decrease the non-recurring costs.
- Ensuring the cooperation of all actors involved towards continuous research and development in key technologies and towards further leading edge research
  - Progress achieved spill over into other sectors and EU regions.
  - Complementing further elements of the EU Horizon 2020 Programme, Member States’ national programmes and through strong European coordination
  - Jointly working towards European societal, economic and environmental goals.
3.7 Spill-over effects of aeronautical industry

Aeronautical technologies are a proven catalyst for innovation and spill-over into many other economic and technological sectors. The main reasons are the severe performance environmental, weight, safety requirements often associated to severe regulatory requirements any aeronautical products shall comply with. As a consequence, historically, after the aeronautical application, with the contribution of large investments, skills and efforts to meet the severe requirements, has been assessed the item incorporating it is extended - often with simplifications leading to cost reduction - to another field allowing it to achieve a competitive advantage and stay on the technology leading edge. Aeronautics has been then first user promoter and of many new technologies or processes which later spread over many other application fields. Some examples: use of lightweight materials -once aluminium, now high temperature engineered materials or composite--; brushless electrical motors; chemical fine milling process; multifunctional optimization methods and simulation or testing techniques to reduce development costs. A comprehensive, well known example are high performance cars: parts, components, design techniques, manufacturing processes are all directly derived from the aeronautical experience.

The condition of aeronautical industry to be the promoter of high performance solutions is very true also in some case where it may appear aeronautics is on the contrary borrowing the results from other sectors such as electronics, ICT, energy. In reality almost none of electronics, ICT or power electronic solutions developed for automotive, consumer electronics, industrial machining, can be “as is” used in an aeronautical case. Indeed, regulation, very different environmental issues, weight constraints are forcing aeronautical industries to fully re-qualify and often re-design those items on complete different technologies and approach because the basic principles used in the original design are not generally suitable to the aeronautical case and performance required.

An example among many possible, a solid state power electronic device from automotive or industrial machining or even trains has very little to do with a similar -only in name- item for the aircraft case: environmental qualification is different (i.e. low pressure not allowing natural convention cooling, then different more refined principles to be used), more severe vibration environment than cars (this avoid to use some fragile solid state materials), electronic interference very severe (shielding is paramount), much higher reliability required (much more rejected parts). Nevertheless, because solid state power devices are key items for future all-electric solutions, aeronautics industry is currently working, -even though enjoying less market appeal than automotive case by suppliers- to develop suitable power electronics devices. When available -hopefully in near future- the aeronautical designed power electronics devices will be reliable, light, thermally advanced, efficient and will be scaled down -to discard unnecessary sophisticated aeronautical requirements- and used by many other sectors. Another example is ‘lean software’ techniques and network solutions developed within ICT. In aeronautics these commercial solutions cannot currently be adopted because certification requirements are much more severe -wireless network is an example- leading to quite totally different approaches.

In conclusion, spill-over is generally from aeronautics towards other sectors, seldom vice versa. Investing to meet aeronautical requirements has so far demonstrated to be an efficient way to advance in applied technologies.

4. Addressing the Innovation Challenge: Clean Sky 2 Set-up

Technological innovation targeted within Clean Sky 2 will be centred on the following topics:
Firstly, and in continuation of Clean Sky efforts: integrated technology demonstrations at large system level.
Additionally, and building upon Clean Sky achievements: new configurations and new vehicle demonstrations at the integrated vehicle level.

4.1 Building on Clean Sky

Clean Sky has demonstrated clear benefits in terms of accelerating technology maturation through its public-private-partnership approach. The first Clean Sky initiative successfully introduces major developments in different systems such as optimized wing designs, new fuselage construction concepts, energy efficient engine architectures, new flight guidance systems, and ‘more electric’ on-board systems.
These technological advances need to be integrated into complete aircraft to render the next generation of air vehicles more efficient and reduce emissions and noise. In addition, new (and non-evolutionary) vehicle configurations will have to be evaluated with flight demonstrators as they will be essential to fulfil the ambitious objectives of Flightpath 2050\(^\text{14}\). Evidence is mounting that conventional aircraft configurations are approaching intrinsic performance limits, as the integration of the most recent technologies (e.g. composite materials and advanced engines) are showing diminishing returns. Aircraft manufacturers now need to explore and validate the potential benefits of new configurations, integrating the innovative components and systems individually matured in Clean Sky.

Therefore, the need today is even greater for industry to take on the risk (at a manageable and financially viable level) of developing materially different, substantially more environmentally friendly vehicles to meet market needs increasingly driven by sustainability, and to ensure their efficient integration at the air transport system level. Clean Sky 2 will continue to use the ITD mechanism when appropriate; its objective-driven agenda to support real market requirements providing the necessary flexibility is well suited to the needs of the major integrator companies. But beyond this, there is an urgent need to demonstrate new vehicle configurations essential to meeting – in full – the ACARE goals for 2020 and to making important steps towards the newly defined Flightpath 2050 and ACARE [2012] SRIA objectives in practice.

To date, in FP7, as well as in the current Clean Sky, demonstrations of improved systems ‘stand separately’ whilst advancements need to be integrated into a viable full vehicle architecture to better understand interactions, risks and synergies. This is the essence of the required shift from a technology readiness [TRL] driven approach to a system readiness [SRL]\(^\text{15}\) driven approach. This need is embedded in the structure of Clean Sky 2. The overall lessons learned from the first Clean Sky will be translated into Clean Sky 2.

Clean Sky 2 innovatively envisages demonstrations and simulations of several systems jointly at the full vehicle level. In addition, it continues the previous structure to further develop each system.

\(^{14}\) ACARE SRIA 2012 Vol1
\(^{15}\) System Readiness Approach to Aeronautics, NASA / DoD 2009. Preliminary Outline – Subject to Participating Company Approvals - 2012-07-20
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4.2 The Structure of Clean Sky 2 - Principles

The structure of Clean Sky 2 features two complementary types of demonstration projects. Integrated Technology Demonstrators (ITDs) from Clean Sky will be continued focusing on airframe, engine and systems, and will build on the excellent results obtained in this first initiative. Clean Sky 2 will include new demonstrations at the higher level of integration of (full) vehicle platforms. These will enable cooperation engaging the whole value chain at highest integration level within research, and at the most challenging complexity levels. By doing this, Clean Sky 2 will enable the ‘system readiness’ [SRL] approach to be taken towards the integration of future vehicle concept in the ATS, and secure the maximum risk reduction possible under research for future market adoption. As in Clean Sky, a dedicated monitoring function spanning all technology development and demonstration will be incorporated.

Thus Clean Sky 2 will make use of the following distinct elements:

- Innovative Aircraft Demonstrator Platforms (IADPs)
- Integrated Technology Demonstrators (ITDs)
- Continued Technology Evaluator (TE)

4.3 Innovative Aircraft Demonstrator Platforms (IADP)

These projects will aim to carry out final proof of aircraft systems to validate their design and functions, on fully representative innovative aircraft configurations in an integrated environment and close to real operational conditions. Since these projects aim to demonstrate research results at the integrated vehicle level, significant resources will be required to integrate new technologies and advanced systems into new aircraft configurations.

To simulate and test the interaction and impact of the various systems in the different aircraft types, vehicle demonstration platforms are proposed covering passenger aircraft, regional aircraft, and rotorcraft configurations. The choice of vehicle demonstration platforms is driven by the understanding of the most appropriate market opportunities in order to ensure the best and most rapid exploitation of the results of Clean Sky 2. In addition, aircraft analysis and integration constraints will be evaluated targeting all products and provided as input and feedback to the Integrated Technology Demonstrator platforms.

The “integrated project” type of approach that a JTI-based research program can provide is not feasible using other instruments typical of the Framework Programme (e.g., Level 1 / Level 2 projects). The IADP approach can uniquely provide:

- Focused, long-term commitment of project partners
- An “integrated” approach to R&T activities and interactions among the partners
- Stable, long-term funding and budget allocation
- Flexibility to address also specific topics through open Call for Proposals
- Guidance to the Integrated Technology Demonstrators on specific experiences, challenges and barriers to be resolved in the longer term.
- A long-term view to innovation and appropriate solutions for a wide range of issues at the same time (e.g.: smart mobility, environmental compatibility, EU R&T leaderships, etc.)

4.4 Integrated Technology Demonstrators (ITD)

In addition to the complex vehicle configurations, integrated technology demonstrators (ITD) will accommodate the main relevant technology streams for all air vehicle applications. They allow the maturing of verified and validated technologies from their basic levels to the integration of entire functional systems. Each ITD orientates a set of technology developments that will be brought from component level maturity up to the demonstration of overall performance at systems level to support the innovative flight vehicle configurations. Three ITDs are required:

- Airframe comprising topics affecting the global vehicle-level design
- Engines for all propulsion and power plant solutions
- Systems comprising on all board systems, equipment and the interaction with the ATS

4.5 The instruments of Clean Sky 2 - Schematic
4.6 From Clean Sky 1 to Clean Sky 2: principles of the transition

A phased approach will be taken to the start-up of Clean Sky 2 projects. In very broad terms, in the first 4 years Clean Sky 1 developed and demonstrated technologies up to TRL5, whilst from approximately 2012, Clean Sky 1 a selection of these technologies are now being subsequently taken to TRL6 system level demonstration, by 2016 at the very latest. In some cases, Clean Sky 1 ITDs will bring a small number of high-potential but still less mature technologies up to TRL4-5 a focused effort during the 2014-17 period. These will not be validated at TRL6 within Clean Sky (1) but can be good candidates for continuation in Clean Sky 2. Clean Sky 1 technologies, where both (i) relevant and (ii) sufficiently mature, in combination with relevant technologies maturated outside Clean Sky 1, form the basis of technologies considered for IADP integration studies.

Conceptually, as is normal in any actual aeronautical (development) program, Clean Sky 2 IADPs will use the TRL based validation in Clean Sky 1 as a start to perform the necessary integration studies in the 2014-2017 timeframe, and will eventually use TRL5-6 validation from the Clean Sky 1 or Clean Sky 2 ITD level as the key input for the configuration and content of demonstrations. The ultimate down-select decision will often however involve other factors depending on maturity achieved in specific technologies and the risks associated to the actual TRL of a sub-system or system.

Following normal aeronautical industrial program practice, only a limited set of Clean Sky 2 technologies that are matured to sufficient TRL after the IADP demonstrator decisions are made will as yet be incorporated into planned IADP demonstrations, based upon evaluation of the pros and cons. There will be technologies not taken forward towards IADP demonstration but with their own clear and sufficient potential for future application; these will in any case be brought to minimum of TRL5 and where feasible TRL6 within the Programme, through the ITDs.

There will be no duplication of Clean Sky (1) and Clean Sky 2 activities for any specific technology or system. The activities within Clean Sky (1) will be pursued until completion according to the plan; then the technology integration may be launched in a Clean Sky 2 IADP or, if the maturity at this point is deemed not sufficient for integration; the technology development will be continued as part of the relevant ITD. An IADP may start in Clean Sky 2 while some of the integrated technologies have not yet passed the final validation tests; the architecture and configuration trade-off studies can be launched in an IADP as soon as the specifications and interfaces of the components and subsystems to be integrated can be frozen.

Consequently the activities within Clean Sky (1) ITDs can be completed according to their own work plan at the latest in 2016 while new activities are launched within Clean Sky 2 ITDs and IADPs according to a staggered schedule starting in 2014 at the earliest.

The completion of Clean Sky (1) in the period 2014-2016 will require large human resources dedicated to manufacturing and testing of demonstrators; while in the same period the Clean Sky 2 starting phase will require only pre-design and architecture and simulation teams to be active; no significant resource overload is expected to result from the two programs running temporary in parallel.

It can be assumed that the partners having successfully developed a certain technology in Clean Sky (1) will be the best qualified to carry on with its further development and/or its integration as part as Clean Sky 2 activities; they will transfer their own IP as background in Clean Sky 2. Should however such a partner decide not to propose any follow-on contribution or should his/her proposal not be successfully selected, and/or
should another partner be engaged to contribute in the integration or further development of a technology without owning the relevant IP, negotiation will be engaged between all concerned parties about conditions for use of the needed background within Clean Sky 2 and no further activity will start until an agreement is reached.

In the figure below, the principles of transition management from Clean Sky (1) to the proposed Clean Sky 2 Programme are shown; However it must be noted that in Clean Sky 2 each ITD and IADP may develop a tailored approach and adopt its own timing because technology details, TRL maturity achieved in Clean Sky 1 or specific needs require modifying the general approach.
5. **Clean Sky 2 – Proposed Programme Content**

5.1 Large Passenger Aircraft IADP

5.1.1 Going beyond *Clean Sky*

The Smart Fixed Wing Aircraft – Integrated Technology Demonstrator (SFWA) in *Clean Sky* is providing the best evidence that an R&T programme seeking to push new breakthrough technologies for large transport aircraft towards applications is greatly enhanced in a framework that allows the conduct of large scale demonstrations on ground, in dedicated rigs and facilities, and with large or full scale flight tests. When combined with associated numerical and analytical studies, and furbished with the related capabilities and capacities to conduct the corresponding conceptual and detailed design work, the inherent uncertainties and risks of new technologies can be most effectively and efficiently understood, technically managed and removed.

Within *Clean Sky*, key technologies for the fuel efficient, low drag “smart laminar wing”, and a number of new technologies to integrate the most efficient, most advanced propulsion systems for commercial large transport aircraft of the future are passing the critical steps of proving and validation in the SFWA. Most of the key technologies in the programme, having typically started at Technology Readiness Level 2 or 3 are, at around half way through the programme, at TRL 4 or 5. As an example in SFWA the target for the *smart natural laminar wing* and a new *low speed vibration load control* is to reach TRL6. For the *innovative noise shielding empennage*, and the *smart flap* the target TRL is 5, and a down selected set of active flow control technologies. For the *in-flight demonstration of the CROR propulsion concept* the target TRL is 4 to 5 “+” as some important items of structural and system integration cannot be validated within the planned lifetime of *Clean Sky*.

One of the key drivers for the implementation of the IADP in *Clean Sky 2* on top of the well-proven ITD - a specific lesson learned from SFWA. Reaching TRL6 for an individual technology through validation and demonstration in ground and flight tests at relevant scale and under operational conditions in a multidisciplinary approach does not typically provide any evidence and proof of the risks and potentials of the technology when integrated with other key technologies at the whole aircraft level. For example - what are the risks and the technical potential when combining, for example, an entirely new wing, an entirely new propulsion system and a new innovative empennage design together? This type of question is the reason for planning the IADP in *Clean Sky 2*, the setup and content of the “Large Aircraft AIDP” has directly emerged to provide the answer to that question.

5.1.2 Challenges to be tackled for Large Aircraft in the Horizon 2020 period
Today, Europe benefits from a 40% share of the global aerospace market with short/medium range aircraft making a very large contribution to this success. The next generation of short/medium range aircraft is key to the future of aviation in Europe. This aircraft type will remain core to air transport and essential to efforts to decrease aviation CO₂ emissions for the foreseeable future. Mounting competition from existing and new entrants means that the European sector can only survive by being a global leader in terms of innovation and product performance, at affordable costs and with high volume availability. A significant part of the current Clean Sky research activity is focused on this aircraft class: e.g. the laminar-flow wing and open rotor propulsion, resulting in flight tests at the level of each separate system.

Clean Sky 2 is building on these latest results and is setting out to provide the required platform in which these research matters can be addressed in an integrated and fully representative manner. It provides the essential next research step of verifying and demonstrating how the potentially promising breakthrough technologies must be combined to effectively reveal their full synergies and their potential for future generations of aircraft. In this regard, the project will be decisive for delivering the required technology innovations that will make these new generations of European aircraft possible. By maturing these technologies on a research platform at European level, it is realising the potential for market adoption in the decade thereafter.

Based on the current market forecasts it is reasonable to project forwards that the large aircraft demonstration platforms of Clean Sky 2 will impact over 75% of the fleet needing replacement from 2025 onwards. They thereby will have a highest possible contribution to the prime Clean Sky 2 environmental and social-economic targets: Protecting the environment whilst ensuring sustainable mobility. In explicit terms it will enable:

- To facilitate the greatest possible environmental benefits of environment protection in terms of reductions of CO₂ emissions per passenger kilometre as well as NOx and noise emissions.
- To allow the entire European aviation value chain to jointly collaborate on integrated platforms. In Clean Sky the large commercial aircraft activities engage 16 separate EU member states. It is reasonable to project that a similar level of engagement will occur for these activities in Clean Sky 2.
- To facilitate maintaining and extending European industrial leadership and to be recognized globally as innovative, sustainable and competitive, thereby delivering the largest contribution to employment and economic benefits.
- To target the most challenging aircraft technology breakthroughs for which well-known market requirements exist and the volume, growth and economic scale will lead to substantial long term investments and the creation of high technology jobs in Europe.
- To de-risk the development of breakthrough technologies and ensuring safety and security, leading to unprecedented levels of safety are set up and continue to improve.
- To align European research and innovation strategies amongst all stakeholders and to allow putting forward efficient research and testing capabilities, technology development and demonstration, with appropriate infrastructure and funding.

5.1.3 The role of the Large Aircraft IADP
By definition, technologies that will be brought into ITD 2 have already successfully passed a prior down selection and have a TRL of at least 2 or 3. In contrast some technologies will be brought into the IADP at TRL of 4 or even 5. This gives the IADP the capacity to deliver technologies integrated in combinations and up to TRL6 over the lifetime of *Clean Sky* 2 as opposed to at the very end.

The explicit role of the Large Aircraft IADP in *Clean Sky* 2 is to provide:

- Target technology scenarios for combinations of technologies.
- A large scale integrated demonstrator platform to systematically mature breakthrough technologies in combination, to achieve a high TRL of typically 6 with the goal to achieve an equivalent System Readiness Level (SRL).
- Large demonstrators on ground and in flight, at size and scale representative for cases of potential future application, with complementary rig and ground tests in wind tunnels.
- The environment to create, establish, mature and calibrate tools and numerical simulation means to facilitate the transfer of results into scenarios different to the test or demonstration cases, and to facilitate “virtual” testing in addition to the designs and physical setups tested on ground and in flight.

The technologies to be taken into the Large Aircraft IADP will be selected in order to feed into the target 2025-2030 technology scenarios:

- Best candidate high TRL technologies emerging from *Clean Sky*, in particular from the Integrated Technology Demonstrators SFWA, SAGE, SGO and Eco-Design.
- High potential technologies injected from other R&T programs, national or European funded, being at appropriately high TRL to be rapidly pushed forward to TRL6.
- Additional “enabler” technologies required to link or combine the technology bricks to be matured and validated.

The key issues to be tackled and answered in reaching for TRL6 are to:

- Fully understand the physical potential of the target technologies in combination
- Demonstrate the maturity of the technology for all operational cases at representative size and functionality, where appropriate with individual feature demonstrators or in combination.
- Exploit the impact and value of technologies for the customer for the full operational lifecycle with respect to reliability, maintenance, for all applicable scenarios of use.
- Understand the value for the passenger and freight, with respect to comfort and operational aspects.
- Answer all questions related to industrial introduction and application with regard to manufacturing, production ramp up, complexity of tooling and related efforts.

In addition, a systematic understanding for dynamically scaled demonstration, namely the physical laws, the range and limits of validity, accuracy and representativeness will be brought together in a dedicated IADP workspace.
5.1.4 Setup of the Large Aircraft IADP towards Horizon 2020 challenges

To be able to most effectively address the scope of challenges towards a next generation large commercial transport aircraft in the context of Horizon 2020, the Large Aircraft IADP embodies three separate areas of integrated demonstrators:

- Large Aircraft IADP Platform 1 “Advanced Engine and Aircraft Configurations”
- Large Aircraft IADP Platform 2 “Innovative Physical Integration Cabin – System - Structure”
- Large Aircraft IADP Platform 3 “Next Generation Electrical Aircraft Systems, Cockpit Systems and Avionics”

Coherence between the three platforms will be provided by a direct link between the platform leads. The technology scenarios, which will set the frame of the demonstrations to be selected, prepared and performed, will be provided by Airbus, to be discussed and adjusted with the participating Consortium Members.

Platform 1 “Advanced Engine and Aircraft Configurations”

Taking the year 2000 as reference for the Vision 2020 “ACARE goals” it was and still is the common understanding that an enormous potential for drag reduction, fuel burn and noise emission for large transport aircraft lies primarily in just a few key airframe and engine technologies provided that the substantial operational and industrial risks can be fully understood and managed.

From a number of major R&T programmes it is well known that a simple plug-in of a new technology to an existing aircraft concept, for example, the introduction of an innovative engine concept, has significant consequences for the entire product with respect to performance, operation and the industrial production and use case. If more than one technology with improvement potential are merged, the consequences to be managed are much more complex and potentially.

Any addition of a major new technology to a currently well-known transport aircraft configuration may lead to the need for significant change of the configuration through most if not all disciplines. Achieving a significant net gain for a future generation aircraft, and combining a number of individual step changing technologies points towards potentially disruptive aircraft configurations, etc. The Advanced Engine and Aircraft Configuration Platform of the Large Aircraft IADP provide the integrated demonstration platform for these combinations of best candidate, highly mature technologies.

Currently there are two candidate propulsion systems able to push the overall aircraft efficiency beyond the state of the art geared turbofan technology with up to double digit fuel burn reduction figures: The Contra Rotating Open Rotor, and the Ultra High Bypass Ratio Turbofan. The integration of each of these propulsion technologies requires major changes to the current aircraft architecture. The integration of a radically new smart wing in combination with an innovative engine concept and other new technologies can only be successfully managed through an integrated validation and demonstration:

Activities in the Large Aircraft IADP Platform 1 are the following:
- Development and deployment of a new methodology to validate “disruptive” new aircraft configurations with respect to design, performance and handling quality at representative scale. Development, qualification and calibration of related new simulation tools through wind tunnel tests, simulation.
- Adaption of virtual testing tools to prepare and accompany large scale integrated testing.
- Full size demonstration and testing of next generation engines/propulsion systems partially or fully integrated into the aircraft architecture with complementary rig or ground demonstration of specific features. Flight test preparation, clearance and testing of new engine configurations and the associated integration.
- Validation of active flow control systems integrated into major aircraft components for a high efficient low drag configuration of next generation aircraft.
- Modeling and multi-functional integration at full system level.
- Complementary technology validation at virtual and physical full-scale.

**Platform 2 “Innovative Physical Integration Cabin – System - Structure”**

For decades, the improvement made in the area of the fuselage main and substructure in combination with the cabin structural and system design were typically limited due to mutual interferences and contradictory requirements. The introduction of a “more” or even “all electric” aircraft architecture has major consequences for fuselage design and cabin system and physical arrangement. More recently, new technologies in this area have been developed and matured in a multidisciplinary manner but still individually.

The approach of the Innovative Physical Integration Cabin-System-Structure Platform 2 is to provide the frame for large-scale complex demonstration, as a segmented feature demonstrator or at full size for validation and testing on the ground. The target is to validate high potential combinations of airframe structures using advanced materials and applying innovative design principles in combination with the most advanced electrical system architecture in combination with the next generation cabin. The driver of this approach is attain up to a double digit fuel burn reduction by substantially reducing the use of secondary energy, applying low weight systems and system architecture and to be able to cash in weight potentials in the structural design of the fuselage and the connected airframe structure.

Major lines of activities are broken up into following work streams:

- New overall airframe architecture and new integration approaches.
- Integration of cabin/systems/structure functions, weight savings and reduced production costs.
- Modeling and multi-functional integration of breakthrough systems.
- New system architectures for more electric aircraft, integration of fuel cells, alternative energy generation, storage and management systems.
- Technology validation at virtual and physical full scale.
- Validation of breakthrough technologies by simulation and physical test beds.
Platform 3 “Next Generation Electrical Aircraft System, Cockpit and Avionics”

A huge potential for improvement for the next generation aircraft is provided by the enormous progress in computer technology, miniaturization of electronics, improvements in power electronics and electrical and data network capability. The advantages to be attained are manifold, in functionality, in performance, in size, in mass, sometimes in cost. The main challenge is to leverage benefits in the individual technologies into major combined advantage at the aircraft level.

In the area of cockpit technology and avionics, the advancements have to be put in combination with the new capabilities and functionalities of future ATM operational procedures, as well in combination with the requirements for a next generation cockpit, taking a gradually changing pilot work profile into account.

Main work packages in Platform 3 will address:

- Simulation and in flight demonstration of partial and full suite new operational cockpit technology (linked to the ATM environment).
- Integrated avionics, increased flight safety, reduction of cockpit workload.
- New avionics validation platform for integration of novel functions in a realistic environment.
- Verification and validation (by simulation, virtual reality, mock-ups) of new avionics functions.
- Integrated all electric systems with power and thermal management.
- Reduction of electric energy, reduced power requirements, thus less fuel consumption.
5.2 Regional Aircraft IADP

5.2.1 Clean Sky heritage and background

Regional aircraft basic features are already the key drivers of a dedicated Integrated Technology Demonstrator (ITD) - Green Regional Aircraft (GRA) - within the Clean Sky Joint Technological Initiative financed and running under FP7.

Clean Sky GRA is addressing the following success factors of a modern regional aircraft:

- Low weight structural solutions. Scope is to contribute to reduce the aircraft weight -thus fuel consumption and associated environmental impact-, and to simplify structural repairs.
- Low external noise solutions applied to critical items such as landing gear, doors and bays, flight control surfaces and specific aircraft configuration to reduce external noise and airport nuisance. The aspect is relevant for regional aircraft because their flight departures and landing are more frequent than larger aircraft in a typical hub airport affecting then airport noise emission.
- All electric solutions are addressed because they potentially improve operative efficiency of on board systems and simplify maintenance and ownership costs so critical for regional aircraft. In turn they contribute to reduce fuel consumption and emissions because electrical systems are more energy efficient and use less polluting materials than traditional solutions.
- Mission and trajectory management is important for regional aircraft because their high take-off and landing rates associated to the relatively slower climbing times have a strong impact on the airport traffic management and in general ATM issues. At the same type available space and costs allowed in regional aircraft is lower than large airliners thus requiring fully compatible solutions at lower volume and cost.

The key technologies of Clean Sky GRA are all coordinated by means of dedicated aircraft configuration analyses and studies performed to compare the different combinations and assess the better solutions. Clean Sky GRA will finally demonstrate and assess those technology potential and performances at system level mainly by means of real scale tests both on ground and in flight.

5.2.2 The challenges ahead for the Horizon 2020 period

The strategic objectives for regional aircraft research and innovation

The further development and maturation of technologies pursued in Clean Sky GRA at a system level requires integration and validation steps beyond what is currently planned in Clean Sky. The actual application of innovative technology in an aircraft as a complex product is pursued only when, as a minimum, the following conditions are met:

- Interfaces and links with the other technologies necessary to the aircraft operation are suitably resolved
- Solutions are acceptable to the market (passenger interfaces and comfort, certification and safety, maintenance process, operating reliability and cost)
- Meeting the criteria for industrial success for the aircraft manufacturing industry (e.g. competitive non-recurring and recurring costs, and a reliable and competitive supply chain).

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16 See also: White Paper: Regional Aircraft Sector, July 2012

Preliminary Outline – Subject to Participating Company Approvals - 2012-07-20

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The need to address the environment (starting from the Clean Sky GRA), as well as mature other technologies necessary for a future regional aircraft to be successful and make a real change towards the strategic objectives set, drives the need for a Regional Aircraft IADP in Clean Sky 2.

The challenges for regional aircraft
The strategic objectives for regional aircraft above are consistent with Flightpath 2050, the White Paper on Transport and set in the ACARE Strategic Research and Innovation Agenda (SRIA).

Namely, regional aircraft will contribute to the following challenges identified:

- Competitive regional aviation will help enable door-to-door journeys within 4 hours’ journey time for 90% of European travellers.
- Innovative regional aircraft will reduce aviation environmental impact offering aircraft suited to the required range and capacity reducing use of overdesigned aircraft on short routes.
- Regional aircraft require little or reduced airport assistance capacity and runway length than large airliners being designed to operate in small regional airports.
- They contribute to a fast, safe and effective mobility from less populated or economically developed areas, namely where infrastructures necessary to other transport solutions are not justified by traffic density, severe environmental consequences or high cost.
- Regional aircraft provide a tangible positive contribution to European export and worldwide leadership in the sector.

The need of an IADP for the regional aircraft
In Clean Sky 2 an IADP is proposed to validate the integration of technologies at a further level of complexity than currently pursued in Clean Sky. Actually, European regional aircraft shall integrate many different technologies and requirements in a product which shall be highly competitive on the performance side and successfully face several international competitors on this market segment.

As discussed in paragraph 2.2, the regional aircraft market is today shared between European aircraft manufacturers and several non-EU ones. While each aircraft integrator is proposing very advanced and effective aircraft and it is aiming to capture market share, non-EU regional aircraft manufactures are enjoying strong national support for technology development.

EU regional aircraft manufacturers need equivalent support to not lose the positive momentum they are experiencing and which is contributing towards recovering the ground lost in recent years. The Clean Sky 2 IADP for regional aircraft has the scope to integrate and validate, at aircraft level, advanced technologies for regional aircraft so as to drastically de-risk their integration on future products, improving the outlook on EU industrial leadership in this sector.

In addition, sustaining the R&T regional aircraft IADP will permit to mobilize a wide EU supply chain thanks to many EU countries with a regional aircraft integration capability (France, Italy, Spain, Poland, Portugal, Czech Republic and Romania) which are complemented by a large supply chain spanning across all EU countries providing dedicated engines, on board systems, avionics suites, structural and material solutions, advanced manufacturing technologies, complex testing facilities as is currently happening in the Clean Sky GRA underway.
The technical aspects faced by regional aircraft IADP
As said the challenges of regional aircraft shall be exploited in the Regional Aircraft IADP harmonizing the different technical aspects and scientific contributions in a way which is aligned with the industrial and market requirements. Each technical aspect to be pursued is inextricably linked to many other technical aspects – some faced in Clean Sky, some others within Clean Sky 2, others coming from regulation or pure market evolution. Nevertheless, the following technical aspects have been identified as key elements for regional aircraft success.

Tentatively, a link is provided with the challenge it mainly answers, even if each technical aspect described addresses more than one challenge as defined earlier.

- **Powerplant** - The combined effect of range, speed as well as route and network served by regional aircraft requires specific propulsion solutions, such as an advanced turboprop powerplant. The effort will contribute to reduce environmental impact and fuel consumption as well as increase the competitiveness of European regional aircraft.

- **Integrated fuselage** - A regional aircraft requires an optimized, with structural advanced low weight solutions, integrated fuselage with adequate space for passengers and baggage. Cost effective solutions for on-board systems will be required. Activity is mainly devoted to advanced structural solutions as well as to improve passenger mobility and comfort providing a seamless flight experience among the different transport means as well as competitiveness of European technologies.

- **Aerodynamics** - Low noise solutions at Take-off, Approach and Landing will be investigated to reduce noise footprint and environmental impacts. This aspect is aimed to reduce environmental impact and to allow completing the journey in 4 hours by a proper insertion of regional aircraft in the new ATM in association with powerplant improvement.

- **Cockpit and Avionics** - Improved functionalities for efficient operations, such as dispatching and maintenance. Space constraints in the cockpit and minimizing pilot workload. The scope is to simplify operations in small airports with limited on-ground aids and build competitiveness and improve safety records of regional aircraft.

- **Maintenance** - Increase in availability and simplification of maintenance and operations are key factors for regional aircraft. The scope is to reduce operative costs and improve competitiveness of European regional aircraft.

5.2.3 Clean Sky 2: taking new steps
The Regional Aircraft IADP demonstrations will be built by integrating solutions from current Clean Sky GRA with several other advanced technologies:

- Those matured in the frame of Clean Sky 2, as: relaxed stability technologies, powerplant technologies, passenger friendly cabin solutions,
- Those matured through other relevant technology development of FP7, such as maintenance, smart energy management, materials, etc.

The demonstration objectives of the Regional IADP are much more complex, comprehensive and challenging than those of the current Clean Sky GRA which was forced to work within budget constraints limiting the
content. Examples of the big steps beyond Clean Sky GRA to be accomplished for the in-flight and on-ground demonstrations are shown overleaf:

- Aerodynamic and aero-acoustic innovative solutions are demonstrated in GRA by means of WTT, whereas the Regional IADP foresees a flight test campaign for low drag, low noise experimental demonstration;
- The all-electric aircraft concept demonstrations in the current GRA are obviously limited by the engine power of the ATR 72 used as flying test bed, whereas for the Regional IADP advanced powerplant technologies might also be integrated on a modified existing wing so as to achieve a meaningful demonstration of powerplant and systems architectures targeting the all-electric regional airplane
- For the structural fuselage demonstration, in the GRA a full scale barrel will be the test article for the ground demonstration limited to structural concepts, materials and processes, whereas in the Regional IADP an almost complete fuselage, full scale, will be used and fully tested
- GRA does not cover the very complex interactions and integration activities necessary to “match” the friendly passenger cabin technologies with the onboard innovative systems architectures: i.e. new electrical distribution and electrical on-board climate control (ECS), with structural solutions and thermal aircraft issues. Whereas Regional IADP will demonstrate those complex interactions.

5.2.4 The regional aircraft action and programme set-up

Innovative and highly integrated full scale demonstrations, allowing acceptable risk and complexity but still providing the requested integration answers, are essential to allow the insertion of breakthrough technologies on regional aircraft entering into service from 2025 on.

The validation of integrated solutions to solve specific technical aspects, as highlighted above, will be explored through a set of advanced full-scale. These will be managed with state-of-the-art techniques and processes for schedule cost and resources control, systems engineering approach and techniques for evaluation of performance and critical design gates, with advanced design tools.

The demonstrations will be divided into three technologically compatible and “scope close” demonstrations:

- Flight Demonstration of Innovative Wing, Tail Planes and Flight Controls technologies
- Flight Demonstration of Wing related Systems and Powerplant technologies
- Ground Demonstration of a full scale innovative fuselage and passenger cabin technologies

These Regional Aircraft IADP demonstrations will use the enabling technologies, validated at system level in the relevant ITDs of Clean Sky 2 and the results at system level of current Clean Sky either GRA or other Clean Sky ITDs. Regional Aircraft IADP will bring them to the highest level of integration deemed necessary before to go-ahead with their inclusion in the baseline configuration of a regional aircraft product.

Each demonstration will pursue, arrange and integrate compatible and related technologies to maximize integration interfaces and full scale meaningfulness whilst reducing cost, complexity and risks. The final definition of the content will be defined considering the TRL available at the decision gate process as well as the complexity and cost associated to each demonstration. Wherever possible, in the next descriptions of Regional Aircraft demonstrations the links and interfaces known at this stage of proposal definition in Clean Sky 2 ITD are highlighted.
Innovative Wing Tail Planes and Flight Controls technologies
Scope is the integration and flight testing of an innovative wing comprising structural solutions and associated aerodynamic solutions for low-drag and noise with morphing and hinge less devices, all supported by new flight control, actuating systems and other typical wing systems.

The flying demonstration will be defined and developed by introducing extensive modifications on an existing regional aircraft to the wing, proper modifications to the tail-planes as well as to the flight controls in order to demonstrate low drag and low noise solutions, comprising the following:

- An advanced morphing and hingeless high-lift concept would be developed in order to strongly reduce airframe noise of conventional T/E flaps, also allowing for mechanical /structural design of the actuation / kinematics system less complex and lighter than conventional devices. The concerned architecture will rely on the adoption and implementation of those technologies, as “Deeply Embedded Smart Actuators” implying the use of Shape Memory Alloy materials and/or “Smart Actuation Compliant Mechanism”, already assessed in the frame of Clean Sky GRA Project and requiring a big integration step for their application on the next generation regional aircraft.

- Gust alleviation active control: on the basis of LC&A technologies assessment and maturation achieved in the Clean Sky GRA Project, an innovative active system based upon an integrated loads control chain (loads estimator modeling, sensors, control laws, advanced actuators) would be developed to allow fast actuation of control movables, in order to prevent from the occurrence of high load factor from gust and maneuvers. The final aim is to avoid that aerodynamic loads may exceed given limits in certain critical flight conditions, so as to optimize the wing structural design for weight saving.

- Relaxed stability: appropriate solutions will be integrated in order to demonstrate the reduction of trim drag.

The opportunity will also be taken to revisit and to optimize all the other wing systems in order to obtain an optimized wing configuration ready for application in the design of next regional a/c products.

A preliminary roadmap of the readiness levels for the innovative wing, tail planes and flight controls technologies is shown in the following table. The table lists the expected average maturation for each key technology. Details of specific entering technologies from current Projects will be provided at the appropriate critical design gates as shown in the paragraph 5.2.6.
This Demonstration will be closely linked with the Airframe ITD, for which intensive interaction and exchanges are foreseen for the solutions developed in the areas of “Next generation cost efficient wing”, “Advanced control for flexible aircraft”, as well as with the Systems ITD in the areas of “Aircraft equipment and Systems” and “ready-to-fly” systems.

Wing related Systems and Powerplant technologies
Scope is the integration and flight testing of regional aircraft advanced systems and powerplant technologies on a modified existing wing. Related all-electric and engine systems will be included as feasible and possible with constraints above defined. Evaluation of new avionic solutions interfacing new ATM systems to wing system and powerplant will be also performed as necessary and possible while reducing risks and complexity.

New advanced powerplant technologies will be adapted and integrated on the flying demonstration. The installation and the integration will be made so as to achieve a highly integrated nacelle. The set of new systems under investigation and candidate to be integrate comprise powerplant technologies such as active vibration control devices to drastically reduce exterior noise and vibrations as well as contributing to reduce noise source enhancing then passenger comfort, or advanced solutions, like a Propeller Autonomous Electrical De-icing system.. The demonstration may include a new engine and propeller depending on TRL readiness and risk analysis to be evaluated at the decision gates of Regional Aircraft IADP and with the related Clean Sky 2 related ITDs. The powerplant, either new or the existing one will interface to an advanced Electrical Power Generation and Distribution System installed onboard in order to perform a full scale demonstration of the all-electric technologies applied to regional aircraft. This effort may comprise - depending on cost and availability of suitable complete systems or components:- Enhanced Electrical Load Management with usage of local ultra/super capacitors as energy buffer during high transitory energy request, Electrical- Environmental Control System, Low Power Wing Ice Protection System, Global Aircraft Thermal Management, Advanced E/E cooling, and Advanced Landing Gear Systems. The concerned systems architectures, targeting the achievement of the all-electric aircraft will rely upon the adoption and implementation of those technologies, as Electrical-ECS, H-WIPS, HVDC Electrical Network, already assessed in the frame of Clean Sky GRA AEA, SGO MAE, ED-EDS, and requiring a big integration step for their application on the next generation regional aircraft.
Cockpit and avionics innovative solutions might be also explored for their correlation with wing systems and powerplant. The scope will be the demonstration of advanced functionalities for more autonomous aircraft as well as new Cockpit Interaction Concepts.

A preliminary roadmap of the readiness levels for the innovative wing related systems and powerplant technologies are shown in the following table. The table lists the expected average maturation for each key technology. Details of specific entering technologies from current Projects will provided at the appropriate critical design gates as shown in the paragraph 5.2.6.

<table>
<thead>
<tr>
<th>REGIONAL IADP DEMONSTRATIONS</th>
<th>KEY TECHNOLOGIES for</th>
<th>Expected Readiness Levels entering into CS2 (from)</th>
<th>Expected Readiness Level at the end of CS2 (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing related Systems and Powerplant Technologies</td>
<td>Powerplant</td>
<td>TRL 5 (SAGE)</td>
<td>TRL 5 (National)</td>
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<tr>
<td></td>
<td>Nacelle</td>
<td>TRL 5</td>
<td>TRL 5 (National)</td>
</tr>
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<td></td>
<td>All Electric Systems</td>
<td>TRL 5 - 6 (GRA-AEA; SGO-MAE)</td>
<td>TRL 3 (MOET)</td>
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<tr>
<td></td>
<td>Cockpit and Avionics</td>
<td>TRL 5 (GRA-MTM; SGO-MTM)</td>
<td>(SESAR; National)</td>
</tr>
</tbody>
</table>

This demonstration will have a very tight cross-link with the solutions developed within both the Engines ITD and the Systems ITD. Furthermore, a strong link is foreseen also with the Airframe ITD solutions, in particular for the “Next Generation Nacelle” technology stream.

**Full scale innovative fuselage and passenger cabin technologies**

Scope is the integration and testing of a full scale innovative fuselage and passenger cabin including all the on board systems and advanced solutions for increasing passenger comfort and safety up to a typical final assembly line completion level. The fuselage will be the full scale demonstration of manufacturing large composite structural solutions associated to the integration issues and techniques necessary for realistic product exploitation.

The structural solutions will be largely based upon the technologies assessed in the Clean Sky GRA LWC that will be further implemented and integrated with new ones which will be developed in the Airframe ITD.

The full scale fuselage will be integrated with systems such as ECS, Thermal Management, Innovative cabin and interiors, Advanced Electrical Distribution, Health Management, Enhanced fire and smoke detection... It will be designed and manufactured in order to demonstrate the Low cost/weight Optimized Structural Configurations, the human based design for Cabin environment and, by means of available EU ground test facilities, it will be fully tested both for the structural aspects and the Thermal Management features.

The demonstration will also take benefit from advanced manufacturing technologies able to minimize lifecycle cost: automated material process control, monolithic structures, structural component minimization, multifunctional materials; SHM from production to service life through testing activity, integrated multilevel/multiscale design platform, low assembly cost production (zero tolerances). The main design drivers and features of the passenger cabin which will be considered in the conception, design and manufacturing phases are Human Factors topics (Anthropometrics, Ergonomics, Illumination, Loudness), Air Conditioning (Humidity air control), Acoustics (Noise & Vibrations, structure damping), Multimedia (flexible
interface with passenger and aircraft In-Flight Entertainment on board service operations), certification rules, post-crash fire worthiness, low assembly production process (zero tolerances).

A preliminary roadmap of the readiness levels for the innovative fuselage and passenger cabin technologies is shown in the following table. The table lists the expected average maturation for each key technology. Details of specific entering technologies from current Projects will provided at the appropriate critical design gates as shown in the paragraph 5.2.6.

| REGIONAL IADP DEMONSTRATIONS | KEY TECHNOLOGIES for Innovative Fuselage and Passenger Cabin Technologies | Expected Readiness Levels entering into CS2 (from) | Expected Readiness Level at the end of CS2
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<tbody>
<tr>
<td></td>
<td>CLEAN SKY</td>
<td>Other Projects</td>
<td>TRL</td>
</tr>
<tr>
<td>Fuselage Composite Structure</td>
<td>TRL 5 - 6 (GRA-LWC)</td>
<td>TRL 5 (TANGO; ALCAS; MAXIMUS; National)</td>
<td>6</td>
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<tr>
<td>Structural Health Monitoring</td>
<td>TRL 5 - 6 (GRA-LWC)</td>
<td>6</td>
<td>TBD</td>
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<tr>
<td>Fuselage Manufacturing</td>
<td>TRL 5 (GRA-LWC)</td>
<td>6</td>
<td>TBD</td>
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<tr>
<td>Systems (ECS, Electrical Distr., etc.)</td>
<td>TRL 5 - 6 (GRA-AEA; SGO-MAE)</td>
<td>TRL 3 (MOET)</td>
<td>5 - 6</td>
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<tr>
<td>Passenger friendly cabin</td>
<td>TRL 3 (National)</td>
<td>4</td>
<td>TBD</td>
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This demonstration will have a very intensive interaction and exchanges with the Airframe ITD, in particular with the solutions developed in the technology streams concerning Innovative Fuselage and Advanced passenger-friendly cabin and will carry on board the many advancements in the concerned areas achieved in several L2s projects run into FP7.

5.2.5 Expected competitiveness impact

The Regional IADP demonstrations, with the selected topics as well as the expected achievement of challenging TRL/SRL targets, will strongly reinforce the leadership and competitiveness of the EU regional aviation sector.
### 5.2.6 Estimated Timeline and Resources

<table>
<thead>
<tr>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
<th>Year 6</th>
<th>Year 7</th>
<th>Year 8</th>
<th>Year 9</th>
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<tr>
<td><strong>ITD Technology Development</strong></td>
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<tr>
<td>RR : Requirement Review</td>
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<td>CER: Concept Evaluation Review</td>
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<td>PDR: Preliminary Design Review</td>
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<tr>
<td>CDR: Critical Design Review</td>
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<tr>
<td>TRR: Test Readiness Review</td>
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<td><strong>ITD related Test activities</strong></td>
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<td><strong>ITD Test evaluation related</strong></td>
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<td><strong>IADP Test activities</strong></td>
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<td><strong>IADP Test evaluation</strong></td>
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<tr>
<td><strong>Manufacturing parts</strong> (Activities into ITD and mainly IADP)</td>
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<tr>
<td><strong>Integration activities, test preparation</strong> (Activities allocated to IADP)</td>
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<tr>
<td><strong>System requirements, manufacturing requirements, proposed design principles, development of technologies and solutions</strong> (Activities allocated to ITD mainly and IADP)</td>
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<td><strong>Design principle approved</strong> (Activities into IADP)</td>
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<td><strong>Continue with the detail design; Models available for starting tooling manufacturing</strong> (Activities allocated to ITD and mainly IADP)</td>
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**Legend:**
- **RR**: Requirement Review
- **CER**: Concept Evaluation Review
- **PDR**: Preliminary Design Review
- **CDR**: Critical Design Review
- **TRR**: Test Readiness Review

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5.3 Fast Rotorcraft IADP

5.3.1 Clean Sky heritage and background

The European Rotorcraft currently enjoys a predominant position on the global, civil helicopter market thanks mainly to the technical excellence resulting from its past investments in research and technology development.

The strong demand that was not curbed by the general economic downturn appears to accelerate in certain market slots concerned with passenger transport and public / ‘para-public’ services. New fast rotorcraft configurations could fulfil better these needs than conventional helicopters due to inherently more efficient aerodynamics. Several non-EU competitors are well prepared as extensive demonstrations and product developments already took place with massive public support for military programs and civil products can be derived quite easily. In parallel, EU industry invested on own funds in order to acquire a limited knowledge and background in the last few years concerning two promising non-conventional configurations: the tiltrotor aircraft and the compound rotorcraft. The reader is invited to refer to section 8.3 in annex of the present document for more details about the specific market drivers and challenges.

Clean Sky JTI’s project activity and progress to date in Rotorcraft

The Clean Sky Green Rotorcraft programme includes in particular the development of advanced active and passive rotor systems; low aerodynamic drag fuselage design; installation of new engines with very low fuel consumption; more electrical on-board energy systems; noise abatement trajectories compatible with rotorcraft operation near the ground in both visual and instrument flight conditions; incorporation of green materials and processes in the construction of typical helicopter parts. These projects also interact with the transversal ITDs: SGO (electrical equipment), SAGE (advanced turboshaft), Eco-Design (green materials & processes, testing of electrical systems). With Clean Sky now reaching mid-life, the technology concept selection phase and system design phase have been completed. Most of the critical design and maturity reviews were successfully passed and realisation of experimental hardware is currently in progress, with only few partial results yet available. Extensive simulations nonetheless give confidence that the combination and integration of the technologies will ultimately allow to reach or even exceed the initially goals and accelerate progress towards ACARE SRA2 overarching goals for year 2020.

In summary, most technologies have to date reached an intermediate level of maturity (TRL3). They are expected to reach a maturity level of TRL5 or -6 through both analytical and experimental demonstration at the end of the programme. Technology maturity achievement will be evaluated by several test bench/demonstrators. These technologies can generally be implemented independently for further development and integration into future helicopters; this will allow industry to carry the remaining risks after confirmation of successful maturation in Clean Sky and pursue with their development and integration into future rotorcraft products, beyond the scope of R&T activities.

For a small number of very challenging technologies e.g. active twist blades or high integrity electrical actuators for helicopter flight control, the maturity will remain low (TRL<5) and the risk too high for implementation; therefore, further research will be necessary for targeting an implementation phase.

The long term, consistent and stable framework provided by the JTI approach of Clean Sky appears instrumental to secure achievement of definite high level objectives for a whole sector namely for rotorcraft environmental objectives: 25 to 30% reduction in CO₂ emission and 50% noise footprint area. A limited set
of shorter-term unrelated projects would have not been able to obtain the same results achieved so far and possibly in the next years to boost the consistent action of EU stakeholders in this field.

5.3.2  The technology challenges ahead for the Horizon 2020 period

The implementation of individual subsystem improvements on conventional helicopter vehicles appears nevertheless to reach its limit and will soon fail to meet the challenges set forth by, on one side a steadily growing demand for high performance and efficient transport and social services, and on the other side the pressing need to reduce further the environmental impact\textsuperscript{17}. The helicopter architecture can be considering as nearly ideal for vertical flight but restricts dramatically its lifting and propulsive efficiency in forward flight beyond 150 to 160 knots when intrinsic aerodynamic limits of current designs are approached.

Non-conventional rotorcraft architectures that feature a fixed wing to unload the rotor at very high forward speeds offer attractive alternatives to helicopter, offering a much higher energetic efficiency in level flight and yielding much longer range and higher cruise speed. Research aimed at high-speed rotorcraft architectures showed that the \textit{tiltrotor} aircraft, where prop-rotors can be tilted from vertical (for hovering) to horizontal for high-speed forward flight, and the \textit{compound} aircraft where one or several propellers provide forward thrust and enables a high horizontal speed are viable solutions to overcome current helicopter limits. Other non-EU industries have been heavily investing on both type of platforms, supported by massive external funding; for the tiltrotor case, the V22 Osprey already in service was developed for the defence sector and it is likely to be marketed in the civil domain very soon, while an advanced demonstration activity was positively concluded recently for the case of the compound helicopter and further developments were announced recently. Industry research and demonstration programs to search for hover efficiency and high speeds in forward flight that can be combined on a single platform, is also complemented by research for maturing enabling technologies in the field of complex system integration, low noise and emissions, operational efficiency, lower cost of operation.

Should the EU stakeholders involved in rotorcraft research and development fail to react adequately, pursuing only incremental improvements of the conventional helicopter, the European global leadership is likely to vanish in a few years. This would imply the loss of its high-end most profitable market shares, the domestic market dominated by foreign products, and loss of highly qualified jobs in EU of OEM and supply chain (which is today estimated in the range of 60.000)

The benefits of R&T investments jointly made by the private and public parties through \textit{Clean Sky} and other public support projects will remain underexploited unless implemented also on these new rotorcraft concepts.

5.3.3  Rotorcraft Demonstration Projects - overview

EU has now the opportunity to respond to the various challenges by tapping the potential of new rotorcraft architectures taking advantage and integrating relevant technologies that have been matured in \textit{Clean Sky} and other programmes for both conventional and advanced configurations.

\textsuperscript{17} See also: White Paper: Rotorcraft Sector, July 2012
Indeed, European rotorcraft integrator industry leaders have been investing their own private funds in both the **compound** and the **tiltrotor** concepts. As a result of studies and experiments including some flights, they hold substantial IP value on two specific configurations distinct from those developed by foreign competitors.

Both configurations combine fixed-wing type forward flight speed with rotary-wing hovering capability, creating superior operational flexibility, even in terms of ground infrastructure. Owing to their specific capabilities, they can target a wide array of missions (passenger transport, search and rescue, emergency services, etc.) and are likely to co-exist in the market, though it is also expected that they will not overlap and will not gain exactly the same type of market.

**It is consequently proposed for Clean Sky 2 the following approach:**

- to design a large or full scale demonstrator for each of the two fast rotorcraft concepts, building on knowledge already acquired by the two major European rotorcraft manufacturers;

- to “federate” the EU supply chain around these two innovative demonstration projects, adapting, integrating and implementing all relevant and mature technologies/systems, including those developed in *Clean Sky* and other programmes, and that will make them cost-effective and exploitable solutions;

- to perform flight demonstrations and compare the results with technical specifications and high level objectives to be established for environmental impact and societal impact;

**Fast Forward Speed Rotorcraft Demonstration Projects – Technology Topics**

*Clean Sky* 2 work scope and programme content will be elaborated to guarantee the natural continuation of specific R&T work packages to reach a higher system readiness level as compared to the current *Clean Sky Green Rotorcraft* (GRC) projects. The introduction of demonstrators in *Clean Sky* 2 will give the opportunity to combine *Clean Sky / Clean Sky 2* R&T results with the availability of flying platforms to validate research results and technical solutions. The combination of the intrinsic aerodynamic efficiency brought by the novel vehicle architectures with the cumulated benefits of individual subsystems provided by *Clean Sky* is expected to allow reaching the environmental goals set by ACARE for the year 2020 while providing enhanced transport productivity.

Some topics in *Clean Sky (1)* that are eligible for continuation in *Clean Sky 2* are:

- Validation of active/passive blade lay-out
- Methods for blade design optimization
- External/internal aerodynamics improvements (aircraft design, numerical simulation and validation, flow control, etc.)
- More and more efficient on-board electrical power
- Innovative power plants
- Low-noise, low-emissions trajectories and flight navigation approach
- Eco-design technologies and processes (recyclable materials, low impact processes, etc.)
Maturation/refinement of full Life Cycle Assessment models (and adopting LCA as one main driver of design, manufacturing, operation, disposal)

In Clean Sky 2 further continued research is warranted into environmental compatibility, approaching aviation and not only aeronautics. In addition to technologies for systems and flying platforms, the opportunity is envisaged to develop greener “mobility models” and the benefits that various innovations may bring to reducing aviation’s footprint on the environment. Assessment of benefits that may come from the use of fast rotorcraft will need to consider several variables like the capacity to respond to mobility needs of society (considering ground transportation system constraints as well), the impact of large ground infrastructures, the exploitation of new navigation systems (e.g., satellite-based navigation), in addition to the direct benefits provided by cutting emissions thanks to vehicle level improvements. One example: rotorcraft landing/take-off sites like airports, helipads, vertiports, have much less impact on a territory or a geographical area in terms of constructions/infrastructures, and much better trajectory friendliness compared to fixed-wing ones. These aspects should be taken into consideration in the ‘equations’ of balance of eco-systems when carrying out the environmental impact assessment of air transport mobility models.

Building on the considerable progress made within Clean Sky to date, a continued programmatic is envisaged, which benefit will be:

- Innovation: in a technology intensive, multi-disciplinary research & technology environment, where complex systems are required to target a market, high-level integrated R&T projects are fundamental to validate – JTI-like Clean Sky 2 can favor this approach
- Environmental compatibility: JTI set of instruments and coordination at EU level on large projects focused on shared targets is the best approach (as shown by Clean Sky)
- EU Leadership: industry and other EU stakeholders (research establishments, academia, etc.) need to balance the strong national support and funding available to industry in other non-EU countries
- EU Collaboration: it is essential to foster collaboration within EU of various stakeholders to favour steady relationships across the Union, leverage effects of funding within each single national countries (i.e., if EU provide enough funding for R&T on large projects/JTI, each country can complement with local funding to sustain specific actions/research, SMEs involvements, etc.), sustaining the R&T capabilities across EU

Technology topics that will be addressed by both demonstrators under different specifications will include:

- Rotors and/or prop-rotors and/or propellers design and optimization for figure of merit and propulsive efficiency and noise & vibration reduction
- Wing structure (including flaps and other integrated functions): design and optimization for general architecture integration, minimum weight, high lift-to-drag ratio, minimum interference with rotor downwash and stiffness
- Fuselage & tail structure: design and optimization for minimum weight, minimum drag (especially rear fuselage, wing-fuselage junction, landing gear integration, tail configuration and surfaces
- Drive system (architecture, design and testing): simple architecture yet advanced configuration for lightweight, reliable and robust-to-failure configuration
- Power plant/nacelles: turbo-shaft engines and intakes/nozzles design and integration
- Flight controls: state-of-the-art fly-by-wire (FBW) with pilot in the loop, with optimization of rotors/propellers thrust/ power required for all the flight phases
5.3.4 Tilt-rotor demonstration action plan

This project will be dedicated to validate an innovative Tiltrotor configuration that goes beyond current architectures of this type of aircraft.

Novel approaches and innovations of the architecture are identified in the following areas/systems:

- **Wing and Airframe/Structure:** wing will host a tiltable engine nacelle (as today) but adding a tiltable portion of the wing itself; this means greater performance/efficiency to current tilt rotors, but it will add complexity and very demanding structural sizing and performance to sustain expected loads, and also additional degrees of freedom to flight mechanics equations and aircraft flight control systems controls laws, thus requiring investigations/validation activities at both aerodynamics/control system level;

- **Engine-Drive System R&T and Integration:** engine will have functionalities that will permit operation in a tilted attitude (e.g., in all attitudes ranging from fully aligned to fully vertical with respect to horizontal plane); this type of engine is not available today on the market at power level required for this application; research activities will validate the engine architecture/systems and its interfaces with aircraft; it is believed that future private investments can sustain further development to generate a family of engines that can feed a wide range of tilt-rotor products, but also turboprop and turboshaft applications for “conventional” helicopters; as today engine manufacturers in this field are non-EU, it is seen favourable to sustain R&T in Europe so that engine manufacturer can recover competitiveness with respect to non-EU countries; the drive system (which provides engine-prop-rotor mechanical link and power transmission) is critical for the operational efficiency of the platform, and addresses several key topics regarding system integrity to guarantee an adequate level of safety; also, another challenge is to provide solutions compliant with functional requirements, safety, but with low cost of operation and of limited weight.

The architectures, interfaces, integration and technologies associated to both the systems needs to be developed in conjunction as the integration of the two is fundamental for the effectiveness of final platform and safety aspects.

- **Prop-Rotor** (propeller when the aircraft flies in airplane mode, rotor when the aircraft flies in helicopter mode): it is the key element of the platform and all aeromechanics (aerodynamics + mechanics + aero-elastic) elements will need to be validated as necessary to clear architecture/configuration/aerodynamic characteristics; the R&T challenge here is that constraints and requirements of the two modes (helicopter, airplane) are difficult to co-exist at the same time, aiming to a cost- and operational-effective solutions.

- **Flight Control System (FCS):** previous EU funded FP6/FP7 R&T programs have not considered this field and system and for the tilt-rotor case in particular, but the complexity of the flight mechanics and control of this type of aircraft will need specific research & technology and validation activities; challenges are in the system integrity and reliability, that must be available in conjunction with a simple architecture, low weight, and integrated with engine/wing control laws; availability of advanced fly-by-wire (FBW) technology is paramount to guarantee functionalities with adequate level of safety.

- **Other Systems:** R&T is expected to be conducted in other various fields like at various level of complexity/innovation: electrical power generation and distribution; advanced cockpits; fuel systems; systems usage and monitoring; low-weight/less hydraulic systems;
Operational Considerations: as a key factor of success of rotorcraft is the possibility to provide various and diversified type of missions using a single architecture/type of platform, the operational considerations of the next generation Tiltrotor becomes fundamental; therefore, the project will include activities to validate operational issues, like the possibility to operate in congested and/or hostile environments, exploiting new air traffic management (ATM) concepts (EGNOS, Galileo based navigation systems).

The approach “per system” of R&T themes of next generation Tiltrotor configuration explained above, will be managed using the following drivers and objectives:

- Define major milestones to increase operational efficiency of Tiltrotors / Fast Rotorcraft platforms (e.g., number of passengers x distance x time, and other efficiency indexes)
- Set the major milestones to reduce the cost of ownership of the platform - note: non-EU studies shows that innovations in the field of aerodynamics efficiency (of prop-rotors, fuselage, etc.), engine efficiency (installation, fuel consumption, etc.), low weight airframe can contribute to improve the direct operating cost x available seat/mile of about 40% to current state-of-the-art Tilt-rotors;
- Define major milestones to keep Tiltrotor / Fast Rotorcraft on the track of Environmental Compatibility requirements for Aviation (on CO₂/NOₓ emissions, noise reduction), including possible integration/applicability/further improvement of technologies and systems/sub-systems solutions developed in Clean Sky (1);

At IADP, the approach to R&T is based on the point of view of the ‘platform integrator’. However, an IADP project needs to be managed by means of strong collaboration with organizations operating within systems/engines/airframe sectors, and with research organizations as well, as they own specific know-how in their respective fields. Hence, the ‘construction’ phase of Clean Sky 2 require specific negotiation and interaction between IADPs and ITDs content to guarantee enough synergy between the two level of project types, among the industrial leaders and ‘founders’ of Clean Sky 2, but also trying to involve other EU stakeholders. In the operational phase of Clean Sky 2, this large involvement of partners will be achieved through Calls for Partners/Proposals.

Therefore it is envisaged the following ‘trans-platform’ collaboration between next generation Tiltrotor project at IADP level with airframe/engine/systems ITDs:

- Engine and engine installation R&T,
- Flight controls/electrical systems (both simulation and integration solutions and testing),
- Airframe advanced solution (low weight, damage tolerant, high strength-weight ratio, low cost of manufacturing),
- Avionics (advanced cockpit solutions, navigation management and operational awareness),
- Research projects for specific system/sub-system, laboratory testing (requiring involvement of research organizations/academia).
The timeline for Tiltrotor demonstrator project will be as follows:

<table>
<thead>
<tr>
<th>Period</th>
<th>Activity</th>
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<tbody>
<tr>
<td>2014-2016:</td>
<td>Studies + platform/systems specifications design</td>
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<tr>
<td>2016:</td>
<td>Critical design review (system/sub-system design freeze)</td>
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<tr>
<td>2016-2019:</td>
<td>R&amp;T activities, test samples, system development/manufacturing, testing</td>
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<tr>
<td>2019:</td>
<td>Flight clearance validation testing completed</td>
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<tr>
<td>2020:</td>
<td>Test Readiness Review + flight/operation demonstration activities</td>
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5.3.5 Compound Rotorcraft demonstration action plan

Based on experience gathered earlier with a low scale exploratory aircraft, the mission requirements for a large or full scale demonstrator vehicle will be established with the aim to combine:

- Large payload capability and agility for hovering flight;
- Long range;
- High cruise speed;
- Low fuel consumption and gas emission;
- Minimal community noise impact.

A pre-project phase conducted in close collaboration with the core partners will allow to define the sizing and individual technical specifications of the main components and subsystems: fuselage, tail unit, wing, engines, mechanical transmission, lifting rotor, propellers and nacelles, control surfaces, actuation system & flight control, vibration & noise control systems, avionics, etc.

During the preliminary design phase, the innovative technologies required for each component to match the specifications will be selected, simulated and developed with feedback to- and interaction with the overall general vehicle project. At the end the preliminary design phase, the multiple interfaces between components and systems will be frozen.

The detailed design and development phase of the components will then be conducted in parallel:

- **Fuselage and tail unit:** the results of previous research programmes concerning in particular composite structures will be implemented and further demonstrated in order to create an extremely light structure using environment friendly materials and production techniques. Aerodynamics is part of the challenge to design a rear fuselage with innovative architecture that enables wide rear access for loading/unloading on ground and in flight (hoisting for rescue operations) whilst securing a low aerodynamic drag. This may require further development and implementation of flow control techniques initiated in Clean Sky (GRC2). The landing gear has to be fully retractable as for a conventional airplane but with specific kinematics to match this airframe particular architecture and with electrical actuation considered as an attractive option for weight saving, taking into account results obtained in Clean Sky (SGO, GRC3) and other programmes. Calls for proposals will be issued to select Partners having expertise to support the development of fuselage and tail unit.

- **Wing:** the wing design specific to this rotorcraft architecture must realise a difficult aerodynamic compromise between high lift-to-drag ratio in level flight and minimal interaction with the lifting rotor in hover and a high structural rigidity to mitigate risk of dynamic problems with the propellers and internal transmission shaft. The interfaces between the wing and upper fuselage and tip nacelles require particular attention, from both the aerodynamic and the mechanical standpoints. The wing
incorporates special flaps that are used to adjust continuously the wing lift according to flight conditions and optimise the overall vehicle performance. Minimising the structural weight is a critical design objective also for the wing and will require designing the structure using most advanced materials and construction technologies. The development of the wing structure will be conducted in collaboration with fixed-wing aircraft industrial partners and may take place in part or totally within the scope of the Airframe ITD.

- **Lifting rotor**: The rotor design has to ensure a high figure of merit in hovering flight similar to that of helicopter rotor and to preserve a high equivalent lift-to-drag ratio at high forward speed, while generating minimal noise and vibration. Such combination may be difficult or impossible to realize without blade active control. Several blade control technologies have been developed in Clean Sky (GRC1) and other programmes; the most appropriate one matching the requirements could be implemented on this rotor. The rotor hub mechanical parts and fairings will be optimized to reduce aerodynamic drag, implementing results of Clean Sky (GRC2). The rotor will be designed to rotate at variable speed i.e. to spin much slower at high forward speed than in hover and low speed.

- **Propellers**: two distinct functions have to be ensured, namely propulsion in cruise flight and aircraft yaw control by left/right differential pitch. Yaw control in hover requires propellers to operate close to zero thrust alternating positive and negative pitch with a response to pitch inputs that need to be quick and as linear as possible. The same design must allow for a high propulsive efficiency in fast flight. In addition, the multipoint optimization has to take into account the rotation speed variations and the objective to minimize the propeller noise in all flight conditions. While meeting specifications for strength and reliability and low cost, the construction of blades and hub parts (propellers, rotor) will also implement the materials and techniques best suited to reduce the environmental impact based on experience gathered in Clean Sky (EDA, GRC6). The propellers will be developed in collaboration with partners having specific expertise.

- **Powerplant**: the compound rotorcraft demonstrator will feature powerplant architecture similar to that of a helicopter, with several turboshaft engines installed on top of the cabin. The power ratings will be specified according to the shaft power necessary to drive the powertrain in a flight envelope representative of missions foreseen for future compound rotorcraft products even though the demonstrator might be sized somewhat differently in order to minimise its cost. The engines could be flightworthy prototypes or modified serial engines and they must feature a very low specific fuel consumption and gas emission (CO₂, NOₓ), comparable to what demonstrated in Clean Sky /SAGE5 and be able to operate smoothly and efficiently throughout a wide range the free turbine speed in order to accommodate the rotor variation across the flight domain. The engine air intakes and exhaust nozzles and cowlings will be specifically designed to match the compound rotorcraft architecture and its broad speed envelope. In order to minimise the drag and installation loss, computational tools and the design methodology proven within Clean Sky GRC2 will be used.

- **Power drive system**: the drive train includes a main gear box coupled to the engine free turbines, to the lifting rotor and to the right and left power shafts that run inside the wing. Each of these shafts is connected to a wing tip gear box that drives the corresponding propeller. Generators and hydraulic pumps are driven by the main gear box with some other accessories driven by each of the wing tip gearboxes. With respect to a conventional helicopter, the main gear box architecture is modified to incorporate the two lateral power drives. The long lateral shafts must tolerate some misalignment due to wing deformation and be able to carry high torsional loads with a high reliability target; innovative design and construction are envisaged in order to make them as light as possible. The design of the whole power train will be compliant with the REACH regulation esp. surface treatments further to technology development performed in Clean Sky (EDA, GRC6).

- **Actuation and flight control system**: this particular rotorcraft architecture provides numerous independent flight control inputs (movable tail surfaces, wing flaps, lifting rotor controls, individual propellers’ pitch, drive train speed) which allow not only to control all aircraft degrees of freedom
(attitude, speed vector) but also to optimise its performance, stability and maneuverability according to flight conditions. A state-of-the-art control system will be designed taking advantage of these multiple inputs to ensure easy control by the pilot with seamless transition between hovering flight like a modern helicopter, to climb, cruise, and descent like a fixed-wing aircraft. The automatic flight control system will take care of optimising the redundant inputs to obtain best fuel efficiency and minimal noise emission while enduring highest standard safety with back-up modes in case of any failure. The decision to install either an electrical or a hydraulic actuator for each type of control will be made mainly on the basis of the weight breakdown taking into account results of Clean Sky concerning electrical technologies (GRC3, SGO, EDS). Calls for Proposals will be issued in order to involve new industrial partners for providing innovative actuators (as required) and research labs to define performance optimisation strategies.

Any system or component that needs not be specifically developed or modified for that demonstrator will be acquired off-the-shelves from conventional helicopter or aircraft inventories in order to minimize the project cost.

All components and systems will be assembled and the demonstrator will be tested on ground (including minimum mechanical endurance). After passing qualification review and obtaining the permit-to-fly, the flight campaign will start with the flight domain opening followed by thorough evaluation of its performance, handling qualities, safety procedures and finally demonstration of its operational capabilities, as far as the limited on-board equipment will allow.

Further development work will then be performed concerning Flight guidance and insertion in air traffic: Minimization of noise impact through dedicated flight procedures was addressed in Clean Sky up to TRL6 for conventional helicopters and for tilt rotor aircraft. The compound rotorcraft’s noise impact during take-off and approach can be modified thanks different combinations of propeller pitch and lifting rotor longitudinal pitch and fuselage attitude. The demonstrator will allow first to evaluate the noise emission of compound rotorcraft as compared to conventional helicopter and tilt rotor aircraft and second, to define and demonstrate flight procedures and flight control strategies enabling to minimize that noise emission while remaining compliant with ATM rules and flight safety standards. The work programme will follow the general methodology established in Clean Sky GRC5 and Calls for proposals will be issued to support the development of flight procedures in liaison Air Navigation Service Providers and ATM research projects.

The timeline for Compound rotorcraft demonstrator project will be as follows:

<table>
<thead>
<tr>
<th>Period</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014-2016:</td>
<td>Studies + platform/systems specifications design</td>
</tr>
<tr>
<td>Early 2017:</td>
<td>Critical design review (system/sub-system design freeze)</td>
</tr>
<tr>
<td>2017-2018:</td>
<td>Component manufacturing activities, unitary &amp; subsystem testing</td>
</tr>
<tr>
<td>End 2018:</td>
<td>Flight clearance validation testing completed; Test Readiness Review</td>
</tr>
<tr>
<td>2019 – Mid 2020:</td>
<td>Flight/operation demonstration activities</td>
</tr>
</tbody>
</table>

5.3.6 Expected impact:

- Industrial leadership and global competitiveness
Non-EU competitors are heavily investing in and are sustained by external funding on both type of platforms; for the tilt-rotor case there is already a platform which is in service in the defense sector and it is likely to be marketed in the civil domain very soon, while an advanced demonstration activity was positively concluded recently for the case of the compound.

On the basis of the complexity, cost, and technological risk associated to such innovative platforms, the risk of the investment for the integrator OEM is very high and also does not provide a level field of playing with other global competitors.

It is expected that combining private industrial investments with substantial and focused public funding on R&T and technology validation, will permit EU to maintain the current leadership in the sector at both integration and system level even in this new emerging field of fast rotorcraft sector; private and public co-funding will be able de-risk the R&T activities for pursuing a market that today is far being established, stable and willing to pay risky research, will permit to proceed with previous preliminary studies, and will sustain the possibility to go beyond from current experimental platforms; alternatively, private investments of EU OEM integrator only will not be able to counteract competitors’ progress, and it will exclude them from the global vertical take-off and landing (VTOL) global competition.

- **Societal Benefit**

  Fast Rotorcraft platforms are providing the answers to request for combining good hover performance with fast forward speed.

  This will permit to provide services and type of air transport with characteristics that are not possible today: rescuing and helping injured people faster; extend the mission capability and flexibility in disaster relief missions; covering the very demanding requirements for transportation to oil & gas platforms, in particular for deep-water platforms; complement current and future air transport (of passengers and freight) with a new “grid” which adds one degree of freedom to ATS with a great potential to exploit new concept of inter-modality.

  In addition to considerations above, sustaining the R&T and demonstration activities will permit to mobilise a wide EU supply chain thanks to the six main countries where the two OEM integrators have their design and research centres facilities which will be complemented by other partners across EU (as happening in current Clean Sky, where 16 countries are involved in Green Rotorcraft ITD).

  In few words, Fast Rotorcraft platforms will provide more speed, longer range, more “productivity” (associated to cost of ownership and operation, like payload x speed), will be able to demonstrate how these configurations will match the needs and requirements of operators, will gain benefit from ground infrastructures, such as a network of helipad and airports and with associated services, will fit new Air Traffic Management requirements, will add degree of freedom to ATS in general, and will make new and more efficient and effective services to citizens.

- **Compatibility with Environment**

  Technical solutions developed in Clean Sky to reduce the emissions will be applied in the design of these new demonstrators aiming to prove the concepts’ potential operational effectiveness at vehicle level and in the European transport system. Targets on environmental compatibility aligned with the current ACARE 2020 agenda and also preparing the longer term Flightpath 2050 targets will be pursued combining technology research in area of platform efficiency (low drag aerodynamics, adaptive rotors, low impact propulsion systems, more electric systems), engines emissions, global life cycle approach.
5.3.7 Contribution to Technology / Impact Evaluation (TE):

The demonstration projects will each provide synthesis numerical models that capture the essential behavior and performance of the rotorcraft demonstrators with possible extrapolation to a larger scale future product. As far as realizable, the tools and methods defined in Clean Sky GRC to create PhoeniX models will be implemented. As necessary, they will be adapted to allow for additional objectives and metrics, such as mobility. The engine manufacturer, research Institutes and academia are expected to support the development of synthesis numerical models and validate them.

5.4 Airframe ITD

5.4.1 Background and Context

Aircraft level objectives of greening, mobility improvement, fulfilment of future market requirements and contribution to growth cannot be met without strong progress on the airframe. On greening the very ambitious CO2 and noise reduction targets of FP2050, which still have to be broken down between airframe, engine and systems, will typically rely for between 30 and 50% on progress on airframe. Improvements on mobility and agility are a shared objective between airframe and systems.

5.4.2 Clean Sky (1) project activity and progress made

Within Clean Sky (1) the SFWA ITD will have demonstrated a more efficient wing with natural laminarity, optimised control surfaces and control systems. Also novel engine integration strategies will have been derived and tested.

Altogether strong progress towards the 2020 targets will have been obtained (estimated at 75% of the relevant part of the ACARE goals); however the applicability is limited in scope (focused on short range / low wing sweep / lower speeds) and further quantitative progresses are required to fully reach the 2020 target and further progress towards the 2050 ones.

5.4.3 The challenges ahead for the Horizon 2020 period

The global aim of the ITD is to demonstrate innovative airframe concepts and architectures up to the integrated system level, and enable their introduction into the next generation of aircraft. Activities are structured around technology streams that will make the best use of synergies across the wide product range targeted by Clean Sky 2 (general aviation, business aircraft, regional aircraft, large passenger aircraft, and rotorcraft) in a cross-cutting manner.

This will bring key support to the European environmental, mobility and industrial leadership objectives targeted in the different IADPs. More precisely the Airframe ITD will bring:
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- Greening through product performance improvements (drag, weight, versatility) and an eco-friendly life cycle,
- Helping to improve mobility and decrease congestion by supporting vehicle developments that improve time efficiency and agility,
- Addressing future market needs with product differentiators making travel greener, more efficient and more pleasant, and making aircraft globally more cost efficient,
- Contributing to European growth and to the preservation of highly skilled jobs thanks to advanced production processes and more efficient design, validation and certification processes.

The Airframe ITD will support technology de-risking at major system level, to be further integrated in the vehicle integrated demonstrators, and is will be one of the enablers of the different IADPs. Nevertheless, it will encompass a wider range of airframe technologies, and mature these, with two key outcomes:

- Complement the technology portfolio of the air vehicle concepts addressed in the IADPs, in particular with next generation solutions
- Insert key enabling technologies specific to other aircraft applications such as business jets, in a systematic approach geared towards vehicle level optimisation. Technological challenges linked to these applications include for example innovative wing concepts, and unconventional fuselage configurations including novel propulsion integration solutions.

The technology streams of the Airframe ITD will not only cover concepts and product definition and demonstrations, but also manufacturing and assembly techniques, modelling and other enabling capabilities, bringing significant improvements to European aeronautic industry efficiency in design and development, and high productivity manufacturing.

Integration issues within a global aircraft concept will be addressed in interaction with relevant aircraft concepts analysis undertaken in the IADPs, and interfacing issues with engines and system components will be managed in interaction with the relevant ITD.

5.4.4 The action and programme set-up needed

Improving efficiency at the airframe level requires two major elements:

- Progress on major airframe components:
  i. Wings: although strong progress has been made within Clean Sky on wing efficiency further improvements are both possible, in particular through integration of aerodynamic and structure innovations and necessary on what remains the main efficiency driver.
  ii. Fuselages: innovations within Clean Sky have been limited to the afterbody, with significant progress in particular on noise. More global aero structural optimisations, and more efficient system integration, including propulsion integration, can lead to further progress on drag, weight and greening (recycling).
  iii. Linked to innovative wings and afterbodies is the possibility of innovative control strategies both at global level (aircraft control) and locally (control of instabilities). Direct gains on
efficiency (weight, drag, agility) are expected; also innovative controls can be the enabler of more efficient configurations (e.g. tailless aircraft, flying wing, etc.).

iv. Passenger cabins have not been addressed within Clean Sky and can bring improved passenger comfort, safety and services, but also significant greening through weight reduction

v. Laminar Flow is the aerodynamics technology with the highest drag reduction potential; within Clean Sky Natural laminarity for M=0.75 aircrafts will be brought to TRL=6. The next step is the increase of Mach number applicability (up to M=0.85 for long range applications) and more extensive applicability on the wing (e.g. inner wing).

vi. Nacelles: progress is also possible on areas such as drag reduction, weight reduction, more efficient integration of thrust reversers, etc.

- Progress on airframe architectures:
- Conventional aircraft architectures have been primarily driven by component characteristics, requirements and performances (e.g. pod engine integration for undisturbed air ingestion, etc.); progress on components and on the understanding of their integration requirements makes new more efficient configurations possible. One example is buried engines.

Therefore the key technology streams proposed are the following:
- Innovative aircraft architecture;
- Innovative fuselage,
- Advanced passenger-friendly cabin
- Next generation cost efficient wing
- Advanced control of flexible aircraft
- Extended laminarity for major airframe components for wider flight conditions
- Next generation nacelles
- Advanced rotorcraft airframe

The technology streams will allow undertaking the significant number of technology developments, depicted in the picture here after, orientated toward their insertion at integrated level into key large airframe systems components, so as not to deliver set of stand-alone technologies, but demonstration of this technologies to be implemented into complex system and to actually contribute to the system global performances.
5.4.5 Technology streams and their objectives

- Reduced weight fuselage architectures with reduced noise transmission
- Laminarity and adequate surface quality for fuselage
- Load bearing and noise absorbing windows materials
- Optimized tailplanes and control surfaces with reduced weight and noise shielding capacities
- Next generation passenger cabin with advanced comfort and increased safety, modular installation, wireless cabin, active and passive noise reduction, multifunction and green materials,
- Integrated maintenance functions, wireless health/condition monitoring, autonomous diagnostic, efficient preventive care, remote/distinct repair and maintenance, intelligent trouble shooting, data repository,
- Operational validation / active and passive noise reduction
- De-risking highly integrated airframe structures at competitive cost

A dedicated range of key enabling airframe technologies

- Turbied engines
- Structural integrated ducts
- Flow control and load control
- High temperature and impact resistant composite
- New layout (multi-functional) of ‘innovatives’ (flight control and lift surfaces)
- Low drag laminar wing including active flow control
- Highly coupled engine airframe integration (fan design, short air inlet, nozzle design)
- Lightweight, high aspect ratio wing with optimized composite
- Flexible wing with distributed control, new control device/systems and innovative control architecture
- Tailored, non-circular fuselage, with multifunctional structures and low cost assembly techniques integrating a next generation cockpit and associated shapes and functions
This consistent set of integrated demonstrators for airframes targets the following key contributions to the societal challenges for a smart, green and integrated transport:

<table>
<thead>
<tr>
<th>Technology stream</th>
<th>Targeted Contribution to smart, green and integrated transport challenges</th>
</tr>
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<tbody>
<tr>
<td>Innovative aircraft architecture</td>
<td>Building on Clean Sky major achievements</td>
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<td>After body demonstration (SWFA)</td>
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<td>Green Concept Regional Aircraft Configurations (GRA)</td>
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<tr>
<td>Innovative fuselage</td>
<td>Fuselage Barrel Ground Demonstration (GRA)</td>
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<tr>
<td>Advanced passenger-friendly cabin</td>
<td>New topic</td>
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<tr>
<td>Next generation cost efficient wing</td>
<td>“Smart wing” demonstration (SFWA)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced control of flexible aircraft</td>
<td>Passive “smart flap” demonstration (SFWA)</td>
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<tr>
<td></td>
<td>LC&amp;A &amp; vibration control devices (SFWA &amp; GRA)</td>
</tr>
<tr>
<td>Extended laminarity for major airframe components for wider flight conditions</td>
<td>Natural laminar wing demonstration (SFWA &amp; GRA)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Next generation nacelle</td>
<td>New topic except for nacelle technology for CROR (SAGE)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced rotorcraft airframe</td>
<td>Green Rotorcraft demonstration</td>
</tr>
</tbody>
</table>

(*) ITD definition assumed running of supporting L2 collaborative research projects for transverses activities on enablers of fast and cost efficient design and manufacturing, as virtual aircraft, certification by models, advanced manufacturing.
5.4.6 Resources

With respect to this objective, each technology stream leads to a major demonstration, with the following demonstration options under consideration:

- Ground demonstration at a representative scale of the airframe component;
- Flight demonstration of a modified platform, incorporating the new system for demonstration in representative flight condition;
- Sub-scale flying demonstrator

Each technology stream incorporates demonstration efforts requiring efforts and resources that are at least similar to the reduced set of major demonstrators of SFWA within the current Clean Sky programme. Compared to SFWA, there will also be a greater number of major demonstrators, in order to introduce new topics, but also to address the larger scope of Horizon 2020 transport challenges, which are not limited to sustainable (environmentally friendly) aviation. The necessary volume of activity for the Airframe ITD is therefore estimated to be about 2 to 2.2 times the SFWA total activity.

5.4.7 Timeline

The airframe solutions above will be developed in synchronisation with requirements from IADPs and target aircraft scenarios, establishing two batches of technology developments for TRL6 within H2020, and a third for TRL6 at later times. In general terms the planning for the entire lifespan of Clean Sky 2 will be the following:

<table>
<thead>
<tr>
<th>Period</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014-2016:</td>
<td>Confirmation / achievement of TRL3 for batch 1 and 2. Achievement of TRL4 for first batch</td>
</tr>
<tr>
<td>2017-2018:</td>
<td>TRL3 for third batch. TRL4 for second batch. TRL5 for first batch, (TRL6 on one or two priorities)</td>
</tr>
<tr>
<td>2018-2022 to 2024:</td>
<td>TRL4 or 5 for third batch. TRL5 for second batch. TRL6 on first and second batch</td>
</tr>
</tbody>
</table>
5.5 Engines ITD

5.5.1 Background and Context

Today Europe’s engine manufacture industry has a remarkable market share in Europe and worldwide aviation. As OEM or as major partners in engine cooperation the engine manufacture industry built up a leading market and technological position. The European engine manufacturers are covering the requirements of all types of aircraft, from helicopter engines as turboshaft engine, turboprop engines for regional aircrafts up to the turbofans for medium range single aisle and long range wide body aircrafts. Engines and propulsion systems are one of the outstanding enablers driving the competitiveness of the whole aircraft. As a consequence the engine industry is a major contributor to the value chain of aviation industry securing a remarkable part of employment in Europe’s aviation industry as a social economical leaver.

From the technical perspective the engine and the propulsion systems is a domain for most challenging technologies. All engineering disciplines as aero- and thermodynamics, combustion science, structures, acoustics and science for light weight and high temperature resistant materials are focused in engine technology. Achieving the ambitious goals defined in Horizon 2020 and Flightpath 2050 for emissions is requesting tremendous efforts in all these disciplines. Looking to the market drivers the superior position in all these disciplines and the capability for introduction the technologies in products in line with market requirements are the key aspects for continuous competitiveness in an industrial environment of growing number of participants.

Extensive research programmes are necessary to keep the technological leadership. An oriented funding is basis for an increasing competitiveness of engine manufacture industry and suppliers in Europe.

5.5.2 Clean Sky (1) project activity and progress made

The six SAGE demonstrators in Clean Sky committed to validate a CO$_2$ reduction of 15% relative to 2000 ACARE baseline, a NO$_x$ reduction of 60% and a noise reduction of 18db at TRL 6. The results to date suggest:

- The NO$_x$ target will be closely approached by the lean burn and the turboshaft demonstrators
- The noise target will be closely approached by the geared turbofan and the large 3-shaft turbo fan and the open-rotor will demonstrate a 6 to 9 EPNdB reduction
- The CO$_2$ target will be exceeded through novel configurations e.g. open rotor, geared turbofan and large increased bypass ratio lightweight turbofan.

5.5.3 The challenges ahead for the Horizon 2020 period

The increasing complexity at system integration level in technology and research programmes is one of the major drivers demanding a more integrative approach towards managing research and innovation. Based on the experiences gained during previous programmes a PPP/JTI approach seems to be the most appropriate type of organisation, bringing together all key players who contribute to the system definition and integration. The aeronautics business cycles are very long, and the industry’s complex and costly R&T is organised with long-term roadmaps. For this reason, the possibility to plan a large research programme for 7 years in Clean Sky 1 has been a real asset for the European aeronautics, as it avoided the risk of discontinuity that could arise with classical L2 calls for proposals.
Clean Sky 1 will demonstrate a TRL4-5 on the open-rotor technologies and further validation will be necessary to reach TRL 6 and commit to these objectives. Engines will remain a vital research area in Clean Sky 2, as major steps in aircraft performance always have and will require substantial contributions from new engine designs; moreover research programmes are necessary in order to prepare the next performance improvements requested by the objectives of Flightpath 2050. The goals for engines in Clean Sky 2 will be:

1) To fully validate (to TRL6) the novel configurations for new narrow body aircraft to reach the full 20% CO₂ reduction targeted for 2020.

2) To validate innovative engine technologies across the whole market (from turbo shaft to large commercial aircraft) to achieve the full 20% CO₂ reduction.

3) To validate new technologies to enable the development of a new generation of turboprop engines to enhance European competitiveness.

5.5.4 The Clean Sky 2 action plan and programme set-up

In Clean Sky 2 the engine manufacturers will continue on this basic roadmap to tailor the research programmes towards approaching the ACARE 2020 targets at full TRL6 at the end of Horizon 2020. These technologies are intended to be introduced in 2025+ depending on the market demands. More details of this basic roadmap are described in the table in 5.5.5. One of the key aspects in Clean Sky 2 will be the broad demonstration of the technologies in either flight demonstration or representative tests on a high system level. The upcoming technologies require a higher level of system integration. An increasing bypass ratio is an obvious indicator of this requirement.

Engine demonstrators foreseen include:

- Demonstration of an advanced short/medium-range aircraft engine for 2025+ EIS. The Open Rotor - currently the most promising concept of Clean Sky - will need further maturation and validation. By 2016, decisive steps will have been made in Clean Sky with respect to pitch change mechanisms, acoustics, vibrations, installation effects and weight. Beyond this, more comprehensive tests must be continued in order to further ‘de-risk’ this novel configuration to enable the conversion to flight worthy engine demonstrators.

- New, Ultra-High Bypass Ratio (UHBR) engine demonstration, including geared architectures (addressing narrow body and wide body aircraft applications): these are promising candidates for CO₂ and noise reduction for large engines, and are also a viable alternative solution to the Open Rotor for medium size applications by presenting a different benefits spectrum (less fuel burn benefit, more noise benefit, different integration to the aircraft). Across all of these engines, demonstration of innovative technical solutions to minimise weight, mitigate NOx emissions and possibly take in account unconventional integration into a new aircraft concept will be critical.
- Demonstration of a new high performance gas generator, capable of integration in a hybrid electrical-thermal engine, for regional turboprop and all rotorcraft applications (conventional, compound, tilt rotor). This gas generator will enable future regional turboprop aircraft configurations with step-change improvements in fuel burn, noise, vibrations and emissions. A 20 - 25 % CO₂ reduction is expected to be demonstrated wrt 2000 baseline. Same benefit range is expected for rotorcraft applications when hybrid sources are combined by this new gas generator.

- Propulsion systems for radical design options will also be considered, such as the hybrid wing body, distributed propulsion, etc. This will be geared towards radical architectures for the ‘2nd wave’ of potential innovations beyond 2035.
## Technology streams and their objectives

<table>
<thead>
<tr>
<th>Engine solutions</th>
<th>Targeted Contribution to smart, green and integrated transport challenges (Engine contribution)</th>
<th>Resource efficient transport</th>
<th>Better mobility</th>
<th>Global Leadership – Product differentiators</th>
<th>Global Leadership – market share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open rotor for new single-aisle aircraft</td>
<td>Building on Clean Sky major achievements</td>
<td>CO₂ emission reduction (25% class)</td>
<td></td>
<td>Potential game changer to dominate medium range market Reduced fuel consumption</td>
<td>European engine industry covers over half the market of single aisle and wide body through OEMs and first tier suppliers <strong>Data to be provided</strong></td>
</tr>
<tr>
<td>GTF engine for new civil aircraft</td>
<td>Level 3: Ground demonstration TRL6 of EIS2025+ technology.</td>
<td>Additional 5% -8% CO₂ vs Clean Sky (20-23% vs 2000 reference), Noise reduction</td>
<td></td>
<td>Leadership in advanced compressor and turbine technology. Wide range of applications across small to large aircraft market Lowest noise solution</td>
<td>High quality-low cost manufacturing in Europe</td>
</tr>
<tr>
<td>Ultra High BPR ducted engine for new civil aircraft</td>
<td>Ground demonstration in Clean Sky</td>
<td>CO₂ and noise reduction</td>
<td></td>
<td>Optimized and innovative engine-aircraft integration Reduced fuel consumption and noise</td>
<td></td>
</tr>
<tr>
<td>Advanced turboprop for single aisle aircraft</td>
<td>Ground demonstration of gas generator / power section</td>
<td>CO₂ reduction by increased thermal efficiency Noise reduction</td>
<td></td>
<td>Support regional and SMR range</td>
<td>New market opportunity for cost efficient and environmentally friendly aircraft High quality low cost manufacturing in Europe</td>
</tr>
</tbody>
</table>
5.6 Aircraft Systems & Equipment ITD

Systems & equipment are key contributors to aircraft performance through the combined optimisation of overall aircraft mission, aircraft energy and thermal management, mass reduction, perceived noise reduction and reduced use of scarce or hazardous materials. In addition, innovative solutions for actuation and motion control will enable flight control systems to unlock the untapped potential of aerodynamics and flight mechanics. A key success factor will be achieving an internal aircraft configuration that optimises system performance across ATA-Chapter boundaries. Use of optimal trajectories on the one hand, and energy harvesting, rethinking the generation and distribution of non-propulsive aircraft energy and implementing smart-grid electrical networks with reconfigurable architectures on the other hand will decrease fuel consumption, and keep European aircraft and equipment manufacturers at the forefront of technological innovation. In the future, the all-electrical aircraft will represent a wide potential for fuel consumption and costs reduction. Electrical equipment and systems must be developed as technology bricks to pave the way for this revolution. Innovative electrical architectures, new landing systems, smart mission management and maintenance systems form some of the areas to be addressed, up to airborne demonstration. While important environmental benefits will emerge from these technologies, they will also address global industrial leadership, as they form key items driving operating costs.

5.6.1 Clean Sky (1) project activities and progress made

With respect to aircraft Systems, Clean Sky (1) was built on 2 main pillars: Management of Aircraft Energy (MAE) and Management of Trajectory and Mission (MTM), globally covering a large number of technologies. Developments and validations were conducted on more than 40 elementary technologies, leading to Technology Readiness Level between 5 to 6 for most of them, and 7 technologies brought up to TRL4 only.

The most significant outcomes cover:

- **For MAE:**
  All-electric aircraft architecture, electric power generation, conversion, control, fuel cells, electric air conditioning and anti-ice systems, nacelle.

- **For MTM:**
  Green trajectories development and optimisation process with applications for large commercial aircraft and regional aircraft, and preliminary demonstration of innovative electric taxiing.

Both Clean Sky (1) pillars have led to the development of significant simulation, tooling and integration/test bench facilities. Although environmental benefits need to be consolidated at aircraft level, and for given mission profiles, an overall estimation of the CO2 reduction provided by Clean Sky system developments ranges from −5 to −9%, whereas noise reductions of −2 to −3 dB for climb and −2dB up to −5dB during approach are foreseen.
5.6.2 Clean Sky 2 actions and programme set-up

Part of the Systems ITD key technology streams considered in Clean Sky 2 are follow-ups from Clean Sky (1) activities with a view to refine, mature and further integrate existing results. New technology streams will answer the wider objectives of Clean Sky 2 in terms of societal and economic impact. In many cases these technology streams will use as a starting point results from previous European or national collaborative projects:

- Electrical and energy management systems
- Electrical air systems and thermal management systems
- Mission management and ATS level functions
- Innovative cockpit environment
- Avionics platform and networks,
- Advanced Cabin systems
- Innovative wing / control surface actuation systems
- All electric landing gear system and autonomous electrical taxiing

5.6.3 Development, integration and evaluation process

The targets of all technology stream activities will be defined with respect to the following assessment and integration steps.

- **Technology level:**
  For all technologies: “Individual” development and assessment of a technology
  - Standalone demonstration in dedicated environment
  - High TRL (5-6)
  - Dedicated evaluation of environmental, societal or economic benefits

- **Integrated demonstrator level:**
  Integrated evaluation of related technologies from one or several technology streams.
  - High TRL (5-6)
  - Consolidated evaluation of environmental, societal and economic benefits. For example, an energy management demonstrator will allow assessment of electrical load management, thermal management at aircraft level; a full cockpit demonstrator will be used to assess crew workload or reduced crew operations, etc. Higher integration will also be proposed, for example the Cockpit and Avionics platform.

- **Ready-to-fly level:**
  In a case-by-case approach: development and supply of “ready-to-fly” parts or subsystems for full integration in IADP-level tests and assessments
  - TRL6
  - Contribution to IADP systems readiness levels (SRL)
These integration and assessment steps are not exclusive. A technology may be evaluated in a standalone mode, then integrated at technology stream level and/or identified as direct added value for one or several IADP.

The “ready-to-fly” approach will strengthen the link between ITDs and IADPs and maximise synergy for common equipment or subsystems. This will allow for a first integration at system level thus reducing integration costs at IADP level and higher efficiency at global Clean Sky 2 level. “Ready-to-fly” systems shall be originating either from Clean Sky (1), already demonstrated at TRL 4 to 6, potentially needing additional developments, or shall be new systems developed in Clean Sky 2. Overall, this will cover at least: electrical subsystems, actuation, landing systems, avionics platform and cockpit devices (screens, HUDs, etc.), specific systems such as positioning systems, sensors, communication/data link equipment or functions, advanced mission management functions (data fusion, advanced FMS, etc.).

5.6.4 Innovative, next-generation concepts

Clean Sky 2 will be mostly focused on demonstration, high TRL and integration to deliver a significant part of the ACARE 2020 objectives. In addition, the availability of state-of-the-art demonstrators and systems in the ITD could be an opportunity to prepare new technologies and step-changes for future systems, or assess alternative technologies in some areas. These activities would take place in the last years of the project with a view to address the medium term goals (2030/2035) of the new ACARE SRIA.

5.6.5 Technology Stream Objectives - Overview

i. Energy

Energy management systems:

In Clean Sky, trade-off studies on on-board energy have shown that segregating propulsive and non-propulsive energy can save fuel burn. In Clean Sky (2), focus will be given to management of on-board energy, non-propulsive energy production and storage, and distribution (electrical, pneumatic, hydraulic and/or mechanical) in innovative aircraft architectures.

These activities will demonstrate the performance of a non-propulsive energy management system in association with the electrical systems, electrical air system and thermal management system. Integration and optimisation should be aligned with IADP’s integration and demonstration phases. The system will focus on proposing optimized solutions through cross-ATA chapter boundaries.

Electrical systems:

Demonstration will further integrate Clean Sky (1) achievements and focus on smart grid electrical networks, upgradeable, updatable aircraft architecture, power electronics, flight controls actuation, etc. These activities will lead to high availability, high-density, low-maintenance electrical systems for all platforms (commercial aircraft, rotorcraft, regional and business jets). Weight and volume of electrical systems will be reduced through optimisation of the global system capacity use.
**Electrical air system and thermal management Systems:**

During *Clean Sky (1)* building blocks of an electrical air system (air cycle machine, vapour cycle compressor etc.) and wing ice protection system components will demonstrate their performance during flight tests. The next step in *Clean Sky 2* will be the integration and optimisation of these components into a high performance system solution.

Similar to the air system approach, the *Clean Sky (1)* “toolbox” has to be applied in a thermal management system architecture that overcomes ATA chapter boundaries with respect to system implementation and furthermore prepares the ground for an inter-system electrical and thermal power management (electrical/thermal coupling). The system will focus on de-centralised, local innovative solutions monitored and managed by the thermal management core. From the TRL4 reached in *Clean Sky (1)*, this stream will develop Thermal Management functions to TRL6.

An integrated “energy” demonstrator will allow for first-level integration of electrical systems and assessment of platform-level issues such as load management, overall thermal management, and degraded modes.

**ii. Mission management and ATS level functions:**

Driven from the “System of Systems” [SoS] level, i.e. air transport, with the need for operating cost decrease, system resilience, passenger-centric operations and links for inter-modality, a radical change in perspective is foreseen, resulting in the need for a large multi-functional concept demonstration. In this respect, the “Management of Trajectory and Mission” project of *Clean Sky* will be continued within a broader remit. Management of Trajectories should seamlessly move to “Management of the Air Network” (airspace and air traffic) and “Management of the Operations” (airline level). Fast, real-time decision support and equally: large scale simulation and test capability will be needed to build the smooth operations and resilience that citizens rightly expect from their aviation sector. It is clear that such developments must be performed with very close institutional links with ATM research that, as assumed in this document, needs to be performed under another research instrument.

Technologies to establish the aircraft as a node of a complex, de-centralized network, where ground-air and air-air communications will allow reduction of ground-based activities and in-built system resilience should be developed through implementing innovative functions:

- **Flight & mission management**: e.g. for « 5D » trajectories (3D + time + fuel burn), support to real-time decision in a complex environment, airport navigation, innovative flight concepts (like flight in formation) and a higher ground to on-board interaction – including strong link with ATM and the global Air Transport System.

- **Cockpit & interactions**: HMI will be designed for the upcoming generation of pilots, with a strong focus on safety, providing the pilot with a simplified environment and allowing focusing on the essentials. All systems/functions contributing to situational awareness will be developed, including communication networks, in order to accommodate comprehensive information about weather, health monitoring, etc.

Ground simulations and flight validations are essential to the development of such technologies.
iii. **Avionics & Cockpit**

**Innovative cockpit environment** will build on results from current and recent research projects. The objective is to fully integrate and demonstrate new human-centred HMI devices and interface systems in a more complex ATM environment, but also to focus on productivity and competitiveness through work on incremental certification, automatic code generation, and customisable, scalable systems.

New navigation and communication functions such as data fusion, enhanced and synthetic vision systems, ATC and AOC links will be integrated and demonstrated. New architectures for system management will be proposed.

Finally, the systems ITD will refine and secure the roadmap to implement reduced crew operations and ultimately single pilot flight.

**Avionics platform and networks:** new architectural avionics platform concepts, addressing more and more aircraft functions, are among the most pressing challenges faced by air transport. Next-generation IMA, use of state-of-the-art multicore, multi-OS processors, wireless avionics, smart sensors, centralised database server and database services are some of the major technologies addressed in this technology stream as well as required tool chains for developments. Transverse topics such as modularity, upgradeability, updatable systems, and unified network approach will be demonstrated. Other system-level needs such as security, privacy, open world interface will be taken into account and drive the integration.

An integrated demonstrator will allow for full operational assessment of crew workload, reduced crew operation, dynamic reconfiguration, degraded modes, etc.

iv. **Advanced cabin systems and functions**

New cabin management system, including passengers’ identification, information system and connectivity, in order to provide customer-oriented service functions, e.g. to ease boarding, and prepare the next generation of cabin safety systems for passengers’ protection.

v. **Innovative wing/control surface actuation system**

The next generation aircraft configurations will be characterised by a bundle of innovative approaches amongst which the use of the following building blocks especially impacting on system and equipment design and performance characteristics: (more) laminar thin wings, active flow control, morphing structural wing elements and multifunctional use of the control surfaces. The system & equipment ITD acts in those areas as an enabler providing the required advanced drive system / devices for flow / lift manipulation supplied from an advanced energy distribution system with engine or non-engine based power sources. It is key that the drive system design ensures operation without impacting on the supply network quality.

In addition competitiveness of the solution is significantly enhanced by designing those drive systems as structurally preassembled “plug & play” modules reducing significantly final assembly line time and cost.
vi. All electric landing gear system and autonomous taxiing

With the integration of new functionally into the landing gear like autonomous taxiing as pursued in Clean Sky (1) landing gear systems will see a breakthrough with respect to competitiveness and efficiency. To allow efficiency and competitiveness to be taken yet further, energy management within the system requires an all-electric approach to all consumption areas:

- Advanced electrical autonomous taxiing (with a direct drive motor with energy recycling) activities currently ongoing in CS 1 are indicating a 3 to 4 % fuel burn reduction potential. The current demonstration will lead to TRL 4/5 with laboratory and simulation test. In CS2, this technology maturity will be brought up to a TRL6 with integration and operational ground testing on an aircraft.
- Integration of electrical steering / taxiing drive / anti-skid / flight control interfaces into a new landing gear handling & control concept
- Electrical extension / retraction systems

The new system concepts will allow weight reduction of the structural members by relieving today's load cases. In addition new materials like new titanium alloys will contribute to the weight saving too. While weight saving translates into less fuel burned / less gaseous emissions noise reduction on ground and in flight/ during approach by design or innovative flow manipulation are additional means of making the system more environmentally friendly.
### Technology Stream Objectives – Table

<table>
<thead>
<tr>
<th>Technology streams</th>
<th>Targeted Contribution to smart, green and integrated transport challenges</th>
<th>Links to ITDs / IADPs / Technology Streams</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Building on Clean Sky major achievements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Management systems</td>
<td>Trade-off studies in eco Design for Systems</td>
<td>Airframe ITD, innovative a/c architectures, all IADPs</td>
</tr>
<tr>
<td>Electrical systems</td>
<td>More Electrical Aircraft in SGO: demonstrations on selected sub-systems</td>
<td>Airframe ITD, innovative a/c architectures, all IADPs</td>
</tr>
<tr>
<td>Electrical air systems and thermal management systems</td>
<td>More Electrical Aircraft in SGO: demonstrations on selected sub-systems</td>
<td>Airframe ITD, innovative a/c architectures</td>
</tr>
<tr>
<td>Mission management and ATS level functions</td>
<td>Green Flight Management functions. Mission optimization</td>
<td>All IADPs</td>
</tr>
<tr>
<td>Innovative cockpit environment</td>
<td>New topic</td>
<td>All IADPs</td>
</tr>
<tr>
<td>Avionics platform and networks</td>
<td>New topic</td>
<td>All IADPs</td>
</tr>
<tr>
<td>Advanced Cabin systems and functions</td>
<td>New topic</td>
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<tr>
<td>Innovative wing / control surface actuation system</td>
<td>New topic</td>
<td>Airframe ITD, next gen. cost effective wing, Regional IADP and Rotorcraft IADPs</td>
</tr>
<tr>
<td>All electric landing gear systems</td>
<td>Electric taxi bench demonstration in SGO</td>
<td>Airframe ITD, innovative a/c architectures, Regional IADP</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Resource efficient transport</strong></th>
<th><strong>Better mobility</strong></th>
<th><strong>Global leadership – Product differentiators</strong></th>
<th><strong>Global leadership – Cost efficiency</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced fuel consumption</td>
<td>Reduced fuel consumption</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced fuel consumption</td>
<td>Reduced fuel consumption</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced fuel burn &amp; waste energy harvesting</td>
<td>Reduced fuel consumption</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel/CO₂ and other emissions reduction</td>
<td>Better efficiency and predictability of ATS</td>
<td>Seamless integration of aircraft in ATC/AOC</td>
<td>All IADPs</td>
</tr>
<tr>
<td>Weight savings, Higher crew awareness</td>
<td>Towards safe operations with reduced crew</td>
<td>Affordable cockpit design</td>
<td>All IADPs</td>
</tr>
<tr>
<td>Weight savings. Enabler for new Functions</td>
<td>Enabler for all new ATS level functions for improved efficiency of operations</td>
<td>Improved modularity. Avionics function development efficiency</td>
<td>All IADPs</td>
</tr>
<tr>
<td>Eco-friendly materials, fuel savings, noise and emissions reduction</td>
<td>Ground handling, dispatch priority</td>
<td>Reduced fuel consumption (3-4%)</td>
<td>Electrical taxiing will represent a new competitive advantage</td>
</tr>
</tbody>
</table>

Preliminary Outline – Subject to Participating Company Approvals - 2012-07-20
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5.6.7 High-level planning

![High-level planning timeline](image)

- Techn. Dvpt
- Integrated demonstrators
- Ready-to-Fly
- Flight tests
- Assessment
6. **Clean Sky 2 – Membership & Governance**

### 6.1 Membership

There will be three distinct Full-Membership constituencies:

- **The European Commission** as permanent member will represent the EU and ensure EU public policy.
- **Leaders** of IADPs and ITDs will commit to achieve the demonstrator programmes and manage these throughout their full duration. IADP and ITD Leaders will be named beneficiaries.
- **Core Partners** (aka Associates) will make a substantial long-term commitment towards a demonstrator programme (within an IADP or ITD); with key competences and technical contributions aligned towards IADP and/or ITD project objectives. They will be granted a strategic permanent role through the steering committee of the activity they join. They will contribute to the global management of the demonstrator and contribute financially with significant in-kind contributions. Based on the requirement for substantial long-term commitment (in particular for large engines, structures, systems suppliers) Core Partners will be chosen through open and Competitive Call Mechanisms, guaranteeing a transparent selection of the best participants.

In addition, other **Partners** will be invited to participate in specific topics and projects in the scope of a well-defined limited commitment. These partners will usually be chosen as a result of Open Calls for Proposals or Subcontracting. They will not be members of *Clean Sky 2*.

All Core Partners and Partners will be selected in a transparent and competitive manner, taking the added value of a wide participation from SMEs, academia, Member States’ enterprise and non-profit research institutions into due consideration.

Membership of *Clean Sky* will be reflected in participation in the Governance of the Programme. The governance, and roles and responsibilities of Members are set out as high-level principles hereafter; however these will need to be developed more fully as the legal setting in Horizon 2020 becomes clear.

### 6.2 Governance Principles

The governance of *Clean Sky 2* and the transition between *Clean Sky* and *Clean Sky 2* will depend inter alia on the *Clean Sky 2* legal basis: new Regulation or amendment of the current *Clean Sky* regulation, new Financial Framework Regulation, other measures stemming from Horizon 2020 Rules for Participation. This legal basis is not yet fully known. However, some general principles and can be set out.

In making use of lessons learnt with the *Clean Sky JU* governance structure and organisational set-up, a streamlining of the operational and financial management of *Clean Sky 2* can be achieved. As a foundational principle, and key to ensuring the efficient and timely establishment of the *Clean Sky 2* Programme, the current *Clean Sky Joint Undertaking* (CSJU) will ensure the global execution of the Programme similar to *Clean Sky* as currently set up. In order to avoid having a long learning phase like in *Clean Sky*, the changes in the rules and procedures will be limited to those stemming from the lessons learnt and to those made necessary by new programme content or by externalities such as the new legal framework.
The CSJU Governing Board will ensure the effective continuation and establishment of Executive Management. The CSJU Executive Director and Team will continue to be supported by the Scientific and Technical Advisory Board (STAB) and the National States Representative Group (NSRG). A General Forum will continue to be used as stakeholder assembly.

The JU will retain the current Clean Sky bodies, with the same outline roles; composition changing where applicable due to new programme content and participants:

- Governing Board
- Executive Director
- Steering Committees (governing ITD and IADP Projects)
- National States Representatives Group (NSRG)
- Scientific and Technical Advisory Board (STAB)
- General Forum of Stakeholders.

As further guidelines, the following mandates are proposed. They are largely in line with the current CSJU principles, thus ensuring continuity of governance.

- **Governing Board:**
  How the Governing Board(s) will deal with respectively Clean Sky and Clean Sky 2, in particular during the transition phase, is as yet undetermined, and will depend largely on the future legal framework. The Clean Sky 2 Governing Board will include at least the EC and the Leaders of each IADP project and each ITD. It will have – by consent of its members – certain Observers with full access to proceedings but no voting rights. As a minimum, the NSRG and EREA will be proposed for Observer status. Besides its legal role with respect to budgets, accounts, rules and procedures, it will focus on the strategy and the achievements of the objectives.

- **Executive Director:**
  The JU Executive Director will be accountable to the Governing Board, and will be empowered for the general execution of the Programme in accordance with the strategy set by the Governing Board. The Executive Director will be specifically responsible and tasked with the operational, administrative and financial management of the Programme through the JU’s own resources. He will, in particular, ensure the sound financial management of the JU; propose strategy and content evolutions to the Governing Board; check the continued consistency of the Projects with the objectives; ensure the technical consistency and synergies across the Projects; monitor the progress of the demonstrations through TRL/SRL progress, the schedule and the risks; and take the appropriate measures through the Grant Agreements. The Executive Team staffing level will take the Clean Sky lessons learnt into account, in order to allow the team to play a full coordination role and to accommodate the Calls for Proposals and other tasks with an improved efficiency. The management of possible “L2” projects externalised by the European Commission will be addressed in a later stage, if and when confirmed.
### 6.3 Transition from Clean Sky (1) into Clean Sky 2

*Clean Sky* and *Clean Sky 2* will run concurrently for up to 4 years: 2014-2017. Consequently, this transition phase must be organized and constructed in detail. However, many items are still open - not yet addressed or pending legal decisions (see above).

The same JU will be in charge of the two programmes. This allows for obvious running cost savings and a proper technical transition coordination, but will result in a more complex programme management. As stated above, the composition and structure of the Governing Board(s) will be one of the key open questions to address in the further detailed elaboration of programme governance.

The JU organization, with in particular its Executive Team, should be in place before the start of operational activities: this is a fundamental lesson learnt from *Clean Sky 1*. Then, each Project within IADP/ITDs should start when feasible (with respect to the availability of the resources within the related members’ organisations) and when needed (with respect to the expected market adoption timescale) – with last commitments scheduled in 2020, and a formal deadline by 2025 for achievement of all financial operations.
The JU staff levels will have to ‘peak’ during this period of programme ‘schedule overlap’ to a higher level than steady-state operations for one single programme. Appropriate measures will have to be discussed with the European Commission in order to adapt the staff rules to the appropriate reactivity.

6.4 Evaluation of Technology Progress: TE / Impact Evaluator

A Technology and Impact Evaluation project organization and infrastructure was and remains an essential element within the Clean Sky PPP, and will be continued. Impact assessments evaluating the performance potential of the Clean Sky 2 technologies both at vehicle level and at relevant aggregate levels such as at Airport and ATS, and currently focused on noise and emissions will be retained. Where appropriate and agreed jointly within the JU Membership they may be expanded to include the other relevant environmental and societal impacts.

Core technology evaluation: the analysis of single or logically grouped technologies on system / vehicle performance will be embedded within the IADPs and ITDs, with the TE taking an integrative and ‘synthetic’ approach focusing on the relevance of the Clean Sky 2 output on the Aviation Sector and simulating Air Transport System Impacts.

The evaluation of the progress of each aircraft demonstration platform (IADP) will be monitored against well-defined environmental and socio-economic benefits and technology achievements. The core aircraft performance characteristics (at the so-called ‘mission level’) will be reported by the IADP, with clear assigned responsibilities, resource and project tasks embedded in each IADP. Reporting the mission level aircraft capability will reside under the responsibility of the leading company. The IADPs will provide verification and validation of the performance modelling, so as to certify validity of performance predictions. Impact Assessment will be the responsibility of the TE / Impact Evaluator and will focus on aggregate impacts.

Major European Research Institutes and other qualified academic and research participants will be selected on a ‘best athlete approach’ for the TE and will ensure its independent approach, and endorse the analysis on behalf of the CSJU Governing Board. The JU Executive Director will continue to be the Chairman of the TE Steering Committee.

6.5 Intellectual Property

The basic principle of the intellectual property structure for Clean Sky 2 is to protect the interests of the industrial participants and secure their competitiveness. In particular for activities resulting in higher TRL technologies, the principles of more stringent IPR rules have to be applied and therefore dedicated reference agreements will be defined to help concerned parties within the rules established in Horizon 2020 but different from the standard practice proposed for lower TRL Horizon 2020 instruments. The rules will be need to be tailored to reflect the new requirements from platform level demonstrators and to protect legitimate industrial interests of the participating partners, as well as adequately reflect the rules of participation and programme governance.
7. Resources

7.1 Clean Sky 2 Requirements

The achievement of Clean Sky 2’s core objectives represents a minimum work scope valued at €3.6 bn. Industry is currently working on the finalisation of the project definitions to match this value. This includes further definition of the technical share of activities between ITD and IADP to get clear and simple input/output and responsibilities.

Additional industrial content relevant to Clean Sky 2 (such as general aviation and/or small regional air transport) could be considered. However, further funding sources would be needed.

Industry is prepared to commit the resources equalling 50% of the total required following PPP principles. As a leverage effect, Clean Sky 2 is expected to mobilise significant further private and national funding to support the wider Flightpath 2050 vision.

However, on the basis of the final Horizon 2020 regulation, the proposal could be revised as regards the work scope and budget.

The predominant part (target 60%) of the available funding will be awarded through open competition based on Calls for Partners, Calls for Proposals (at least 25%), Tenders and competitive selection as defined by the Leaders and Core Partners. The calls will be managed by the Joint Undertaking of Clean Sky 2. These calls will be open to all eligible parties including named beneficiaries from other ITDs or IADPs.

7.2 Other Horizon 2020 Aeronautics projects

In response to the commission’s proposal to externalise parts of the collaborative research programmes, Clean Sky 2 would be a suitable place to administer and execute the Commission’s programme for in-scope, Level 2 collaborative research projects.

Participation and governance rules for embedding the management of Level 2 projects in Clean Sky 2 should follow best practice experiences in FP7 and be fully congruent with Horizon 2020.

The Level 2 projects could be synergetic with Clean Sky 2 – particularly in addressing the ACARE SRIA objectives for the intermediate timeframe (2030-35).

The accommodation of Level 2 projects can aid in creating overall coherence to the aeronautics research domain, and ensure a synergistic overall approach across the mid to high level TRL activity. Nonetheless it needs to be realized that doing such within Clean Sky 2 will require Level 2 projects to be accompanied with additional funding beyond the IADPs and ITDs.