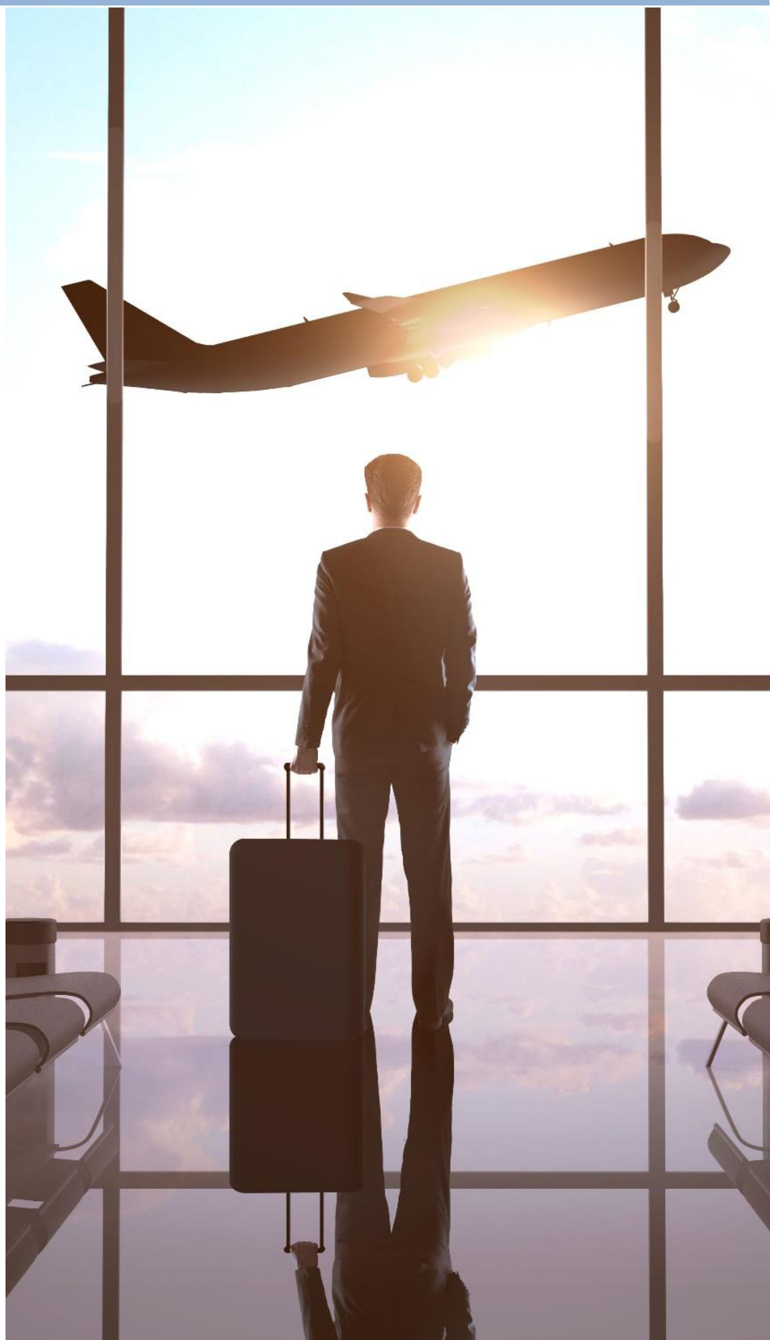
PERSPECTIVES FOR AERONAUTICAL RESEARCH IN EUROPE

Perspectives for Aeronautical Research in Europe 2019 Report



CHAPTER 3

Maintaining and Extending Industrial Leadership

Final Report

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Chapter 3 - Maintaining and Extending Industrial Leadership

In order to maintain and extend its leading position in the aeronautical sector (3.1), the European industry must master each of a wide range of technologies (3.2) as well as their integration in an aircraft design and development program (3.3).

3.1 Retaining and Strengthening Market Share

Flightpath 2050 goal 6: "The whole European aviation industry is strongly competitive, delivers the best products and services worldwide and has a share of more than 40% of the world market".

The European aeronautical industry has achieved and sustained a-near peer position with its worldwide competitors in the most important sectors:

- The Airbus-Boeing 'duopoly' dominates the market for jet airliners of more than 120 seats, with a full range of narrow and wide body aircraft;
- ATR is a leading supplier in the regional aircraft market;
- Airbus Helicopters (formerly Eurocopter) and Agusta-Westland are market leaders in helicopters;
- Safran and Rolls-Royce rival Pratt & Whitney and General Electric in aero-engines:
- In the equipment sector Liebherr, Safran, GKN and others are major suppliers of European and non-European aircraft;
- Dual-use and specific technologies ensure an equally strong position in the world market for military aircraft, missiles, space launchers and satellites.

These impressive achievements across the full range of aeronautical products depend on:

a. Leading-edge technologies in all the sectors contributing to the design of aeronautical vehicles;
b. Integration of all these cutting-edge technologies into efficient aircraft production, certification and service support programmes.

These two aspects (a. and b.) are detailed in the next two sections (3.2 and 3.3). The aviation sector combines competition and collaboration in a worldwide context (Key Topic T3.1).

KEY TOPIC T3.1 - COLLABORATION STRUCTURE OF AEROSPACE FIELD BASED ON WEB OF SCIENCE DATABASE

For understanding the dynamics of a scientific field co-occurrence analysis is applied. In this report, it is aimed to visualize the Aerospace Engineering field based on three categories: Country, institution, and Web of Science categories. By the way, international scientific collaboration networks can be demonstrated nationally and institutionally and studied sub-fields can be determined. All visuals were prepared by using VOSviewer software.

Data is downloaded from Web of Science Database by using the "WC= ("Aerospace, Engineering")" query with last ten years limitation. By the way, 57.982 publications in the Web of Science Category in the last decade is reached.

International Collaboration Networks

The first visual prepared for the understanding of the international collaboration network is presented in Figure 3.1:

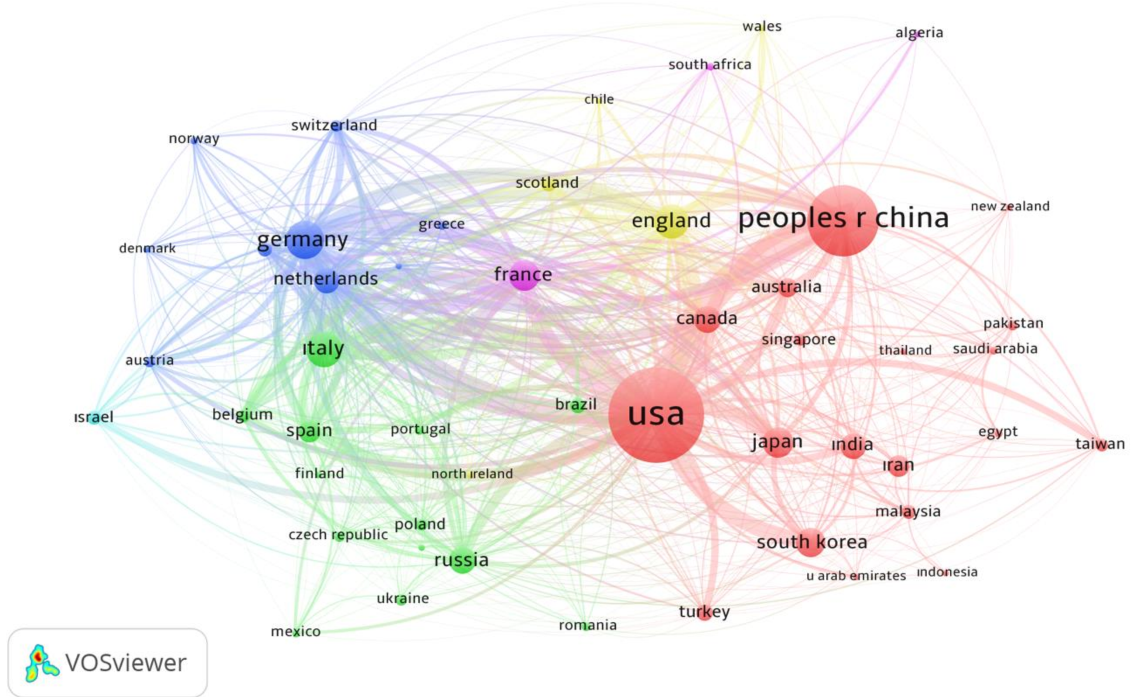

Figure 3.1 - International Collaboration Networks with Document Frequency

As can be seen in Figure 3.1, there are 6 clusters demonstrated with different colours. The node size is showing the publication frequency. It is clear that the largest frequency is coming fromUSA. It can be asserted that European countries dominate four clusters except Israel's and the USA's. England, France, Germany, Netherlands, Italy, Spain, Belgium, Switzerland can be determined main actors in their clusters. This may be understood as the created innovation policy in EU level should be more diffusion-oriented not mission-oriented, because it is thought that national technological capabilities of aerospace engineering may not be collectivized but information and experience may. So, multi-objective policies may be more suitable than one. Hence, every cluster can gain excellence in different subfields and the experience and knowledge may be aggregated in a shared platform for aviation industry of the EU. Moreover, from Figure 3.1, it can be interpreted that, China's development may be analysed specifically to give insight for developing EU Aerospace Innovation policy also.

Collaboration Network of Institutions

The second visualization was prepared to understand the institutional collaboration network worldwide and is demonstrated in Figure 3.2:

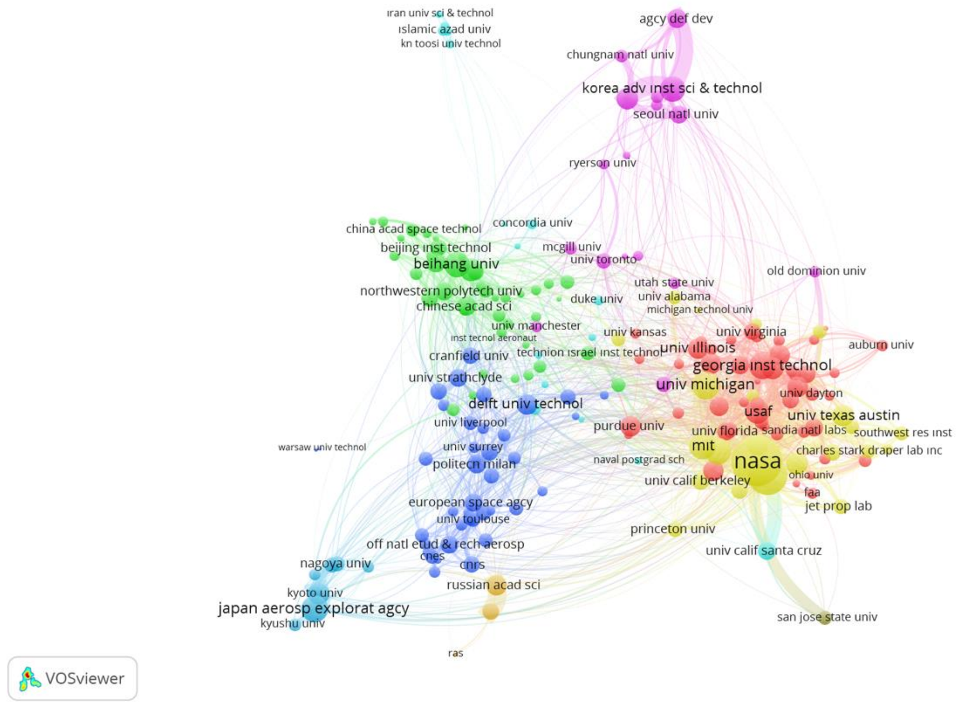

Figure 3.2 - Institutional Collaboration Network

As can be seen in Figure 3.2, there are many universities and research centres located on the map. The European cluster can be identified here with the blue coloured group. Two clusters consist of American universities and research centres. One is dominated by NASA and the other one is shared by some universities and United States Air Force.

Collaboration Networks in Aerospace Engineering Sub-Fields

Finally, the last visual was prepared for the understanding of the research space of aerospace engineering by using the co-occurrences of the different web of science categories. The prepared visual is demonstrated in Figure 3.3:

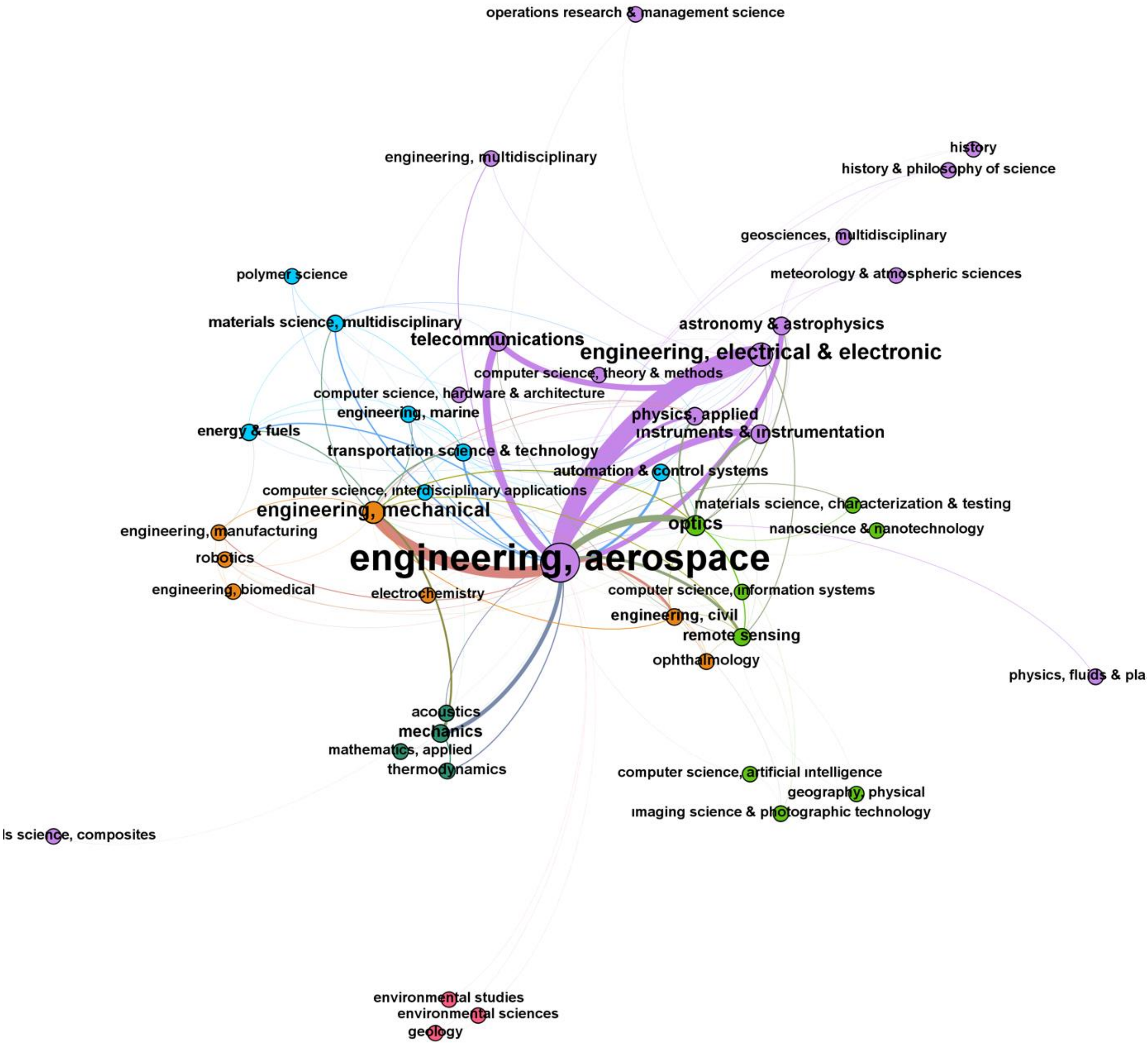

Figure 3.3 - Collaboration Networks Based on Web of Science Categories

Naturally, the main web of science category is aerospace engineering and it is the central node of the network. Clusters are covering these fields; 1. Mechanical engineering including biomedical engineering, robotics and manufacturing; 2. Physics, automation, telecommunications, electric-electronic and computer science; 3. Materials science optics, Nano-science, remote sensing; 4. Energy, polymer science; 5. Acoustics, thermodynamics; environmental studies, geology. From the visual, it can be asserted that physics, computer science and materials engineering are intersection fields. Therefore, including these fields may boost collaborative studies while preparing funding policy for aerospace innovation.

3.2 Cutting-edge at the Full Range of Technologies

**** Flightpath 2050 goal 7: "Europe will retain leading edge design, manufacturing and system integration capabilities and jobs supported by high profile, strategic, flagship projects and programmes which cover the whole innovation process from basic research to flight demonstrators".***

The design of a successful aircraft does not tolerate any less than first-rate solutions in an extensive range of 10 technologies. Only a few examples of each are given:

- Flight physics: This covers the most efficient aircraft designs, either refinements of the conventional tube-and-wing configuration whose development potential is not yet exhausted or more radical designs (flying wings, joined wings, flush or buried engines, hybrid and distributed propulsion) that hold greater promises and challenges.
- Aerodynamics: Advances in Computational Fluid Dynamics (CFD), wind tunnels and flight testing, concerning optimization of overall aircraft configurations and critical aspects like wing design, laminar flow, turbulent transition, shock waves, vortex wakes and their interactions;
- Propulsion systems including prop-fans and open rotors, high by-pass ratio turbofans, turboprops and turboshafts, hybrid and distributed propulsion over a wide range of thrust and power usable in various flight regimes;
- Lightweight structures able to withstand flight and landing loads, resist flutter and incorporate load alleviation features, with acceptable production and maintenance costs;
- Selective use of the most appropriate metals, alloys, composites, ceramics and other materials for airframes, engines and highly stressed or intensely heated components;
- Efficient production methods allowing fabrication and joining of sub-assemblies with tight tolerances and high-quality finish;
- Avionic systems including sensors, emitters, receivers, power supplies, signal conditioning and other features relevant to optimal navigation, weather and hazard detection and the accomplishment of a variety of missions;
- Integrated control for flight stability of high gain responsive systems, digital engine control, structural load alleviation, automatic navigation, safety protection and other features;
- Distributed, centralized or embedded computation and data processing capabilities in open architectures amenable to the incorporation of new components to enhance performance without degrading safety and reliability;
- Telecommunication systems for navigation and seamless integration into ATM, data exchange with the ground and other platforms, with resistance to jamming, electromagnetic interference and cyber-attacks;
- The whole range of support equipment including electric, pneumatic and mechanical actuators, air conditioning and pressurization, undercarriage and control of movable surfaces, fault diagnosis and ground support.

Since a substandard mastery of only one of these technologies can cripple an aircraft design and doom its market prospects, it is imperative to keep at the forefront of all these 10 technologies to avoid being caught off guard by a competitor. Also, these technologies must be ready for integration in new competitive products at any time required to maintain market leadership in a new development programme (section 3.3).

The competitiveness of the aerospace industry depends on mastering cutting edge technologies over a wide range of subjects (Key Topic T3.2). An indicator of innovation in aviation as in other sectors are the patents in related subjects (Key Topic T3.3).

KEY TOPIC T3.2 – CUTTING-EDGE AT THE FULL RANGE OF TECHNOLOGIES

Introduction

Modern Europe is facing a number of challenges, among which is the introduction of innovative technological solutions to the European aviation market. The necessity to introduce new technological solutions results from the needs of society, new technologies that have appeared and new types of transport means and air transport systems.

Societal needs should be understood, among other things, as:

- The growing demand for air transport services,
- Expectations of increasing the availability of transport services (geographical, economic, etc.),
- Reducing the impact of air transport on people and the whole natural environment,
- Improvement of safety,
- Others.

New technologies that have appeared should be understood, among other things, as:

- New materials and fabrication technologies,
- New types of power units,
- New types of energy storage sources,
- New information technologies,
- New design technologies,
- New technologies in the area of management,
- Others.

New types of means of transport and air transport systems should be understood, among other things, as:

- Implementation and integration of flights of manned and unmanned aircraft in the common airspace,
- New air transport systems (small air transport system, sat system),
- Vertical take-off and landing aircraft,
- New take-off and landing technologies,
- Others.

The answer to these challenges is the two aviation programs currently being implemented in Europe.

The first one is Clean Sky 2, the largest European research programme developing innovative, cutting-edge technology aimed at reducing CO2, gas emissions and noise levels produced by aircraft. Funded by the EU's Horizon 2020 programme, Clean Sky contributes to strengthening European aero-industry collaboration, global leadership and competitiveness.

The second one is SESAR 2020, demonstrating the viability of the technological and operational solutions already developed within the SESAR R&I Programme (2008-2016) in larger and more operationally-integrated environments. SESAR 2020 will prioritise research and innovation in a number of areas, namely integrated aircraft operations, high capacity airport operations, advanced airspace management and services, optimised network service performance and a shared ATM infrastructure of operations systems and services. Additionally, in order to cope with the expected evolution of air traffic, SESAR is planning to go one step beyond the 2020 vision concerning to airspace management, based on a digital environment highly connected and automated. In 2019 SESAR publish its vision for the future digital architecture of ATM "A proposal for the future architecture of the European. SESAR 2019". This study proposes a progressive transition strategy towards the Single European Digital Airspace System in three 5 year-periods, while building on known good practices and quick wins, as well as existing initiatives such as SESAR.

2025	2030	2035
New programmes on airspace re-configuration and operational excellence deliver quick wins. **Regulation evolution to support the transition ahead**	Implementation of the next generation of SESAR technologies completed with the roll-out of virtualisation techniques and dynamic airspace configuration Gradual introduction of higher levels of automation support. New architecture enables resources (including data) to be shared across the network	Network operates at its optimum capability having fully evolved from a system based on punctuality to a system based on predictability across a network that can safely and effectively accommodate 16 million flights (+50% compared to 2017).

Table 3.1 – Transition strategy towards the Single European Digital Airspace System

In order to initiate the transition towards a Single European Digital Airspace System, the following three recommendations were made:

1. Launch an airspace re-configuration programme supported by an operational excellence programme to achieve quick wins;
2. Realise the de-fragmentation of European skies through virtualisation and the free flow of data among trusted users;
3. Create a legal and financial framework that rewards early movers.

In addition to the two main programs, smaller programs were accomplished or are currently developing, solving some of the selected problems mentioned before. Among them it can be pointed:

- EPATS (European Personal Air Transportation System) continued in the frame of Small Air Transport Roadmap (SAT-Rdmp),
- FUSETRA – Future Seaplane Traffic
- GABRIEL (Integrated Ground and on-Board system for Support of the Aircraft Safe Take-off and Landing),
- ERA (Enhanced RPAS Automation).
- AGILE
- CAPPADOCIA
- EBSF_2 – EUROPEAN BUS SYSTEM OF THE FUTURE 2

Clean Sky 2

The Clean Sky 2 Programme consists of four different elements, as shown in Figure 3.4.:

- Three Innovative Aircraft Demonstrator Platforms (IADP's) for Large Passenger Aircraft (LPA), Regional Aircraft and Fast Rotorcraft, operating demonstrators at the vehicle level,
- Three Integrated Technology Demonstrators (ITD's), looking at Airframe, Engines and Systems, using demonstrators at the system level,
- The Technology Evaluator (TE), assessing the environmental and societal impact of the technologies developed in the IADPs and ITD's,
- Two Transverse Activities (Eco-Design, Small Air Transport (SAT)), integrating the knowledge of different ITDs and IADP's for specific applications.

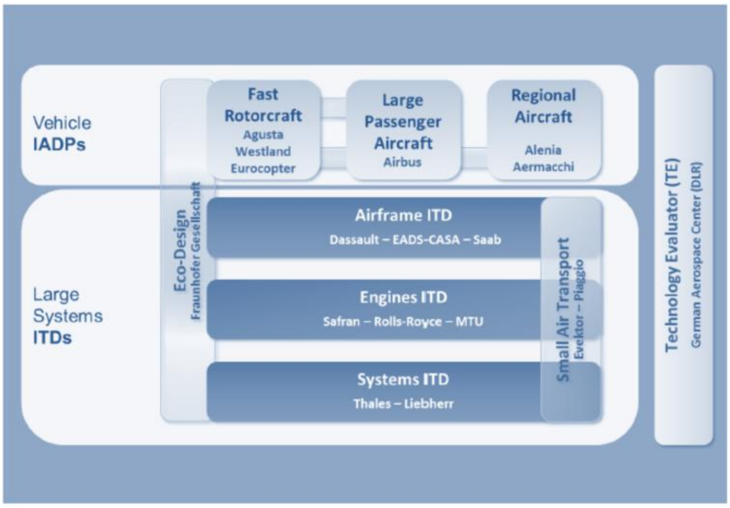

Figure 3.4 - Structure of the Clean Sky 2 Programme (CS2, 2015)

Large Passenger Aircraft IADP

Large Passenger Aircraft's goal is a high-TRL demonstration of the best candidates to accomplish the combined key ACARE goals with respect to the environment, fulfilling future market needs and improving the competitiveness of future products. The focus is on large-scale demonstration of technologies integrated at aircraft level in three distinct 'Platforms':

- Platform 1 "Advanced Engine and Aircraft Configurations"
- Platform 2 "Innovative Physical Integration Cabin – System – Structure"
- Platform 3 "Next Generation Aircraft Systems, Cockpit and Avionics"

Regional Aircraft IADP

Regional aircraft are a key element of Clean Sky through a dedicated ITD - Green Regional Aircraft (GRA), providing essential building blocks towards an air transport system that respects the environment, ensures safe and seamless mobility and builds industrial leadership in Europe.

The following demonstration programmes for regional aircraft a/c are now foreseen:

- 2 Flying Test-beds (to minimize the technical and programme risks) using modified existing regional TP a/c with underwing mounted engines, for demonstration campaigns of air vehicle configuration technologies, wing structure with integrated systems and propulsion integration; flight dynamics, aerodynamics and loads alleviation, advanced flight controls and general systems, and avionics functionalities.
- 5 Large Integrated Ground Demonstrators: full-scale wing, full-scale cockpit; full-scale fuselage and cabin; all including their associated systems; flight simulator; iron bird. In addition, a Nacelle ground demonstrator will be done in the Airframe ITD.

The Demonstration Programme will be divided into technologically compatible and "scope close" demonstrations sub-programmes:

- FTB1 - Innovative Wing and Flight Controls (Regional IADP)
- FTB2 - Flight Demonstration of a highly efficient and low noise Wing with Integrated Structural and related Systems solution, including power plant aspects (Regional IADP)
- Full-scale innovative fuselage and passenger cabin (Regional IADP)
- Flight Simulator (Regional IADP)
- Iron Bird (Regional IADP)
- Ground Demonstration of the wing (Airframe ITD)
- Ground Demonstration of the Cockpit (Airframe ITD)
- Nacelle ground demonstration (Airframe ITD)

Fast Rotorcraft IADP

The Fast Rotorcraft IADP consists of two separate demonstrators, the Tiltrotor demonstrator and the Compound Rotorcraft demonstrator.

The Fast Rotorcraft IADP consists of two concurrent demonstrators, the Tiltrotor demonstrator and the Compound Rotorcraft demonstrator along with transversal activities relevant for both fast rotorcraft concepts.

Airframe ITD

Aircraft level objectives on greening, industrial leadership and enhanced mobility, and the fulfilment of future market requirements and contribution to growth cannot be met without strong progress on the airframe. Within Clean Sky, a more efficient wing with natural laminarity, optimised control surfaces and control systems, will have been demonstrated. Also, novel engine integration strategies will have been derived and tested, and innovative fuselage structures investigated.

Programme major Technology Streams:

- Innovative Aircraft Architecture, to investigate some radical transformations of the aircraft architecture.
- Advanced Laminarity as a key technological path to further progress on drag reduction, to be applied to major drag contributors: nacelle and wing.
- High Speed Airframe, to focus on the fuselage & wing step changes enabling better aircraft performances and quality of the delivered mobility service, with reduced fuel consumption and no compromise on overall aircraft capabilities.
- Novel Control, to introduce innovative control systems & strategies to gain in overall aircraft efficiency.
- Novel Travel Experience, to investigate new cabins including layout and passenger-oriented equipment and systems.
- Next Generation Optimized Wing Boxes, leading to progress on the aero-efficiency and the ground testing of innovative wing structures.
- Optimized High Lift Configurations, to progress on the aero-efficiency of the wing, engine mounting & nacelle integration for aircraft who needs to serve small, local airports thanks to excellent field performance.
- Advanced Integrated Structures, to optimize the integration of systems in the airframe along with the validation of important structural advances and develop and to make progress on the production efficiency and manufacturing of structures.
- Advanced Fuselage to introduce innovation in fuselage shapes and structures, including cockpit & cabins.

Engines ITD

The following platforms or demonstrators are now foreseen:

- Open Rotor Flight Test,
- Ultra-High Propulsive Efficiency (UHPE) demonstrator addressing Short/Medium Range aircraft market,
- Business aviation/Short-range regional Turboprop Demonstrator,
- Advanced Geared Engine Configuration (HPC and LPT technology demonstration),

- VHBR Large Turbofan demonstrator,
- Very High Bypass Ratio (VHBR) Middle of Market Turbofan technology,
- The Small Aero-Engine Demonstration.

Systems ITD

The Systems ITD in Clean Sky 2 will address these challenges through the following actions:

- Work on specific topics and technologies to design and develop individual equipment and systems and demonstrate them in local test benches and integrated demonstrators (up to TRL 5).
- Customisation, integration and maturation of these individual systems and equipment in IADPs demonstrators.
- Transverse actions will also be defined to mature processes and technologies with potential impact on all systems, either during development or operational use.

Technology Evaluator

In summary, the Technology Evaluator consists of three major tasks:

- Progress Monitoring of Clean Sky 2 achievements vs. defined environmental and societal objectives;
- Evaluation at Mission Level by integrating particular ITD outputs into TE concept aircraft/rotorcraft models;
- Impact Assessments at Airport and ATS Level using IADPs and TEs concept aircraft/rotorcraft models.

Eco-Design Transverse Activity

Eco-Design will aim for a roadmap of excellence, to provide high (European) individuality in quality and eco-compliance in the aeronautics vehicles9, in their whole product life.

Key Eco-Design & Recycle themes:

Identification and Life Information Strategy, MPR, manufacture & production, services to component and system (MRO, Finances/IT Know-How, limited life and extended life integration, inside-outside gate synergy processes), Integration/field-assembly-disassembly-separation, RE-Use, End of Life, Alternative Sectoral Applications, Use Phase (TE feed-back, vehicle utilization closure; eco-values).

Small Air Transport (SAT) Transverse Activity

The SAT Initiative proposed in Clean Sky 2 represents the R&T interests of European manufacturers of small aircraft used for passenger transport (up to 19 passengers) and cargo transport, belonging to EASA´s CS-23 regulatory base.

The approach builds on accomplished or running FP6/FP7 projects. Key areas of societal benefit that will be addressed are:

- Multimodality and passenger choice.
- Safer and more efficient small aircraft operation.
- Lower environmental impact (noise, fuel, energy).
- Revitalization of the European small aircraft industry.

SESAR 2020

The SESAR Vision identifies improvement areas where operational improvements supported by technical solutions will bring performance gains that yield the overall performance expected in Single European Sky High-Level Goals as set out in the European ATM Master Plan. These goals being a threefold increase in ATM capacity, improve safety by a factor of 10, 10% reduction of the effects on the environment and a reduction of the cost for ATM services by 50%.

The realisation of the SESAR target concept follows strategic orientations described by four Key Features:

- Optimised ATM Network Services – its features will include activities in the areas of advanced airspace management, advanced Dynamic Capacity balancing and optimised Airspace User operations/UDPP. Innovative solutions are needed to better understand and improve the robustness (resistance to perturbations including meteorological perturbations) and resilience of the network.
- Advanced Air Traffic Services - the activities under Advanced Air Traffic Services will address enhanced arrivals & departures, separation management, enhanced air & ground Safety Nets and trajectory and performance-based free routing. RPAS will be integrated into controlled airspace, enabled by suitable technical capabilities and procedures. Their trajectories are planned as compatible with the ATM network and provide an appropriate level of awareness for ATC.
- High Performing Airport Operations - the activities under this feature will address the enhancement of runway throughput, integrated surface management, airport safety nets, total airport management and remote tower for multiple airports. As airports remain one of the most significant bottlenecks in ATM and therefore represent great potential for system-wide improvement a significant focus will be placed on realising improvements.
- Enabling the Aviation Infrastructure - the enhancements described in the first three Key Features will be underpinned by an advanced, integrated and rationalised aviation infrastructure providing the required technical capabilities in a resource-efficient manner. This feature will rely on enhanced integration and interfacing between aircraft and ground systems, including ATC and other stakeholder systems such as flight operations and military mission management systems. Communications, Navigation and Surveillance systems, SWIM, Common Support Services and the evolving role of the human will be considered in a coordinated way for application across the ATM system in a globally interoperable and harmonised manner. Currently, RPAS operations are not routinely integrated into the ATM environment. The successful integration of RPAS, General Aviation (GA) and Rotorcraft with the commercial air traffic is a major activity in this feature.

Beyond SESAR 2020

In addition to the 2020 vision, SESAR is planning to go one step further in the way airspace is managed currently, in order to cope with the expected evolution of air traffic. According to SESAR, in the coming years, the future European transport system will be an intelligent system highly connected and automated, which will rely on technological advances and enhanced services. In this digital future, SESAR intends to build and modernize the right air traffic management infrastructure to support operations to harness the potential of the sector.

This aviation infrastructure will be built on safe and secure solutions characterised by:

- Higher levels of autonomy and connectivity of all air vehicles
- Advanced communications, sensors and navigation services that provide real-time trajectory information
- Digital and automated tools onboard the air vehicle itself
- Big data analytics and open source data usage that allows better flight planning, airport operations and increased predictability of the overall traffic.
- System modularity to allow easier upgrades and greater interoperability as well as system flexibility to handle an increasing number of vehicles.

In order to achieve the previous objectives, SESAR will take as a base several pillars that foster a collaborative and innovative model. One of these key factors is bringing new entrants to the aviation system (digital start-ups, SMEs, academia, research centres, other industries) and setting up a collaborative environment between them and the established aviation players. The result will be a new way of public-private partnership which blends corporate and academic values, giving rise to innovative ideas. Additionally, other SESAR's pillar is the acceleration of the innovation lifecycle from 30 years to 5 years (e.g. remote towers, extended arrival management, in a way that allows being more agile and responsive to emerging trends. All these aspects will be based on extensive worldwide outreach through cooperative agreements with key regions and relevant organisations.

OTHER PROJECTS

A few projects outside the Joint Undertakings (JUs) Clean Sky and SESAR are given as examples:

EPATS

Date: 2007-01-01 to 2008-06-30

The EPATS (European Personal Air Transportation System) focused on the future Highly Customer Oriented and Time and Cost-Efficient Air Transport System. It fills the niche between Surface and Scheduled Air Transport. Future mobility cannot be satisfied only through investments in a hub and spoke, or rail - and highway systems.

This future EPATS system will provide a wide choice of transportation mode - and the wider use of small aircraft, served by small airports, to create access to more communities in less time.

The goal of the EPATS proposal was to demonstrate the needs and potential of small aircraft business development and to propose recommendations for the introduction of this new European Air Transportation System in the context of the European Research Areas.

The EPATS study will address the following issues:

The potential new market for personal aviation up to 2020.

- The potential impact of this new way of transport on the European ATM, and airport infrastructures, as well as the environmental, safety and security issues involved.
- The EPATS general specification and R&D Roadmap
- The studies will be carried out by a Consortium supported by representative experts of the EPATS stakeholder community.

The deliverables of these studies were rapports containing a joint vision of the personal air transportation system in Europe to 2020 and proposals for developing this new small aircraft business at a European level.

The EPATS SSA proposal fitted in the framework of FP6-2002-Aero-2.

SAT-Rdmp

Date: 2011-01-01 do 2013-03-31

The Small Air Transport (SAT) focuses on the new affordable, accessible, energy effective component of Air Transport System (ATS). It fills the niche between Surface Transport and Scheduled Large Aircraft Air Transport.

This future SAT system will provide enlarge choice of transportation mode, and the wider use of small aircraft served by small airports will create access to transport to more communities in a cost-effective way and in a short time.

The goal of the SAT-Rdmp study (CSA-SA) proposal was to improve the understanding of the commercial role that small-size aircraft operating on scheduled or non-scheduled flights, as a component of the Air Transport System, in order to satisfy the needs of transportation in regions where transport networks (especially surface transport) are underdeveloped.

Main issues of the SAT-Rdmp study (CSA-SA) proposal were:

- Definition of a common vision of the small aircraft transport system for inter-regional mobility through the identification of the corresponding requirements. The requirements will identify the technology needs and regulatory issues to be addressed.
- Definition of a business case compliant with the identified requirements which describe the relations among all the system's components.
- Assessment of current capabilities versus the ATS demand, collection of previous results and involvement of the stakeholders in Europe among all actors (manufacturers, research establishment, European Aviation Safety Agency (EASA), airspace users, infrastructure providers, airport managers, small aircraft service providers).

- Definition of a roadmap to fill the technology/regulatory/operative gaps to fulfil the requirements considering the current capabilities. Identification of dissemination actions and the establishment of a network of stakeholders.
- Assessment of risks and benefits of the identified new system's concept.

The SAT-Rdmp study (CSA-SA) was a very important tool to support the European Commission in defining appropriate actions and a roadmap to implement the Agenda for Sustainable Future in Business and General Aviation. This was recommended by the EU Parliament Resolution on 3rd February 2009.

The SAT-Rdmp study (CSA-SA) was building the European synergy in that segment of Air Transport System and was created European General Aviation Community by discussing, agreeing, finding a common approach of European Key Players: Users, ATM, Manufacturers, Regulators, Research establishments.

The SAT-Rdmp study used the results from the previous EPATS (European Personal Air Transportation System) project. It also kept in close contact with the PPLane (Personal Plane) project funded by the Commission. Organisations that were involved in the EPATS and PPlane projects were also involved in SAT-Rdmp. This prevented a situation that studies were done twice and were ensure that SAT-Rdmp is complementary.

The SAT-Rdmp (CSA-SA) proposal fitted in the framework of FP7-AERONAUTICS and AIR TRANSPORT (AAT)-2010-RTD-1 Topic AAT.2010.7-12 "Assessing and further developing the role of small aircraft in the air transport system".

FUSETRA

Date: 2009.12.01 - 2011.08.31

The general objective of the FUSETRA project was to demonstrate the needs and to quantify the potential of seaplane traffic business development, and to propose recommendations for the introduction of new seaplane/amphibian transportation system, in the context of the European Research Area like the improvement of passenger's/customer's choice for better time and cost-efficient travel and transport. The main objectives were:

- Identification of possibilities to improve seamless travelling by the implementation of seaplane transportation systems within the European air- & landside transportation infrastructure (connectivity of possible seaplane harbours to other means of transportation).
- Development of solutions which will be ready for implementation by ensuring passenger acceptance (Evidence of seamless travel, flight time reduction, reduced operational cost, reduced travel charges, operational safety, better access to international air traffic).
- Identification of the reduced environmental impact of air transport by developing solutions for point-to-point seaplane operations (De-congestion of major airports, seaplane routes over uninhabited areas).

- Propositions for enabling uniform implementation (EC wide) of the chosen seaplane operational system (Regulatory issues, water landing fields, etc.).
- Improvement of the accessibility of regions by serving business as well as private mobility by new seaplane/amphibian connection.
- Identification of the number of seaplanes or amphibians needed to replace existing aeroplanes and needed to satisfy the potential new demand.
- Improvement of trans-national co-operation by organising international workshops.

FUSETRA contributed substantially to the objectives of the EC policies, society and the scientific and technical objectives of the aeronautics priority in particular by organizing international workshops and by inviting all relevant stakeholders as political and public authorities, decision-makers, research communities, industries. FUSETRA contributed to the integration of old and new EC member states. The venues of Greece and Poland were intentionally chosen as being an ideal location to integrate the new member states in South-East and North-East Europe. This procedure supports building networks and tight cooperation's, too; and allows a wide distribution of crucial information on FP7. Partners and stakeholders of the new and old Member States have the possibility to network and to give examples of their experience and achievements by giving papers or participating in working groups with specific work packages. Seaplane operators and industrial stakeholder were mainly small and medium-sized enterprises. The workshops and the technical objective to prepare an action plan and road map for future seaplane traffic systems were particularly addressed to those companies. FUSETRA was directly linked to the vision 2020 of the aeronautical strategy ACARE. Two objectives of the ACARE research agenda were in the focus of this proposal. With new concepts for sea parks and scheduled flights of Seaplane/amphibian operations and its integration to the sea/air/land transport chain, this proposal contributed to "novel solutions for efficient airport use and connecting air transport to the overall transport system" and will "increase the time efficiency of air transport".

GABRIEL

Date: 2011.09.01 - 2014.08.31

The future air transport system will be confronted with new challenges: it must be safer, greener and more effective than the current system. There will be more global industrial competition and fossil fuel reserves will diminish leading to increased fuel prices. New radical ideas, methods and technologies are needed to respond to these challenges and to keep Europe world leader in aviation. One of the ideas that came from the Out of the Box project was to launch and recover aircraft by using ground-based power. Several ideas were proposed like using microwave power technology, hoisting aircraft in the air, aircraft carriers type of aircraft launch and recovery etc.

The GABRIEL proposal was based on a system using magnetic levitation technology to enable aircraft take-off and landing. This unique solution will reduce aircraft fuel consumption since aircraft weight can be reduced as no undercarriage will be needed, less fuel needs to be carried on-board and engines can be smaller as less thrust is needed. Using ground power will also reduce CO_2 and NOx emissions at airports whilst noise levels can be substantially reduced since only airframe noise will be produced during take-off. Airport capacity can be increased by introducing multiple launches and recovery ramps thus alleviating the problem of limited runway capacity in Europe.

Gabriel was investigated if such a system is feasible and cost-effective.

Magnetic levitation is already a developed and deployed technology in rail transportation. However, research is needed to prove the technical feasibility of the concept of air transportation. GABRIEL was investigated how to adapt the existing magnetic levitation technology and to redesign the aircraft and more particularly its fuselage. The project also studied the feasibility of launch and recovery in connection to operating limits and aircraft flight controls. Operational and safety issues were studied extensively. A small-scale test was designed to validate, assess the feasibility and estimate the limits of the assisted take-off and landing concept. The issue of emergency landings was addressed.

The project also performed an extensive cost-benefit analysis, covering the effects on fuel savings, environmental benefits, new airport infrastructures and the required power supply.

The GABRIEL was a typical "out of the box" project that involved 12 partners from 7 European countries.

ERA

Date: 2015.02.12 – 2019.12.30

The project will support the use of military and civil RPAS in non-segregated airspace in Europe. It will also help in the integration of RPAS in airport operations to address capability gaps that have been identified in the European RPAS steering group roadmap for RPAS air traffic insertion.

The project will work with the European Organisation for Civil Aviation Equipment (EUROCAE) to develop draft standards, with collaboration from stakeholders including the Eurocontrol and European Aviation Safety Agency (EASA). The project will also work towards establishing European standards that will offer technical grounds for the certification of auto-taxi, automatic take-off and landing and automation and emergency recovery functionalities.

To achieve the project goals, technical and procedural solutions will be developed, and demonstrated by simulations and flight trials.

ERA is a European Defence Agency (EDA) ad-hoc project launched by five Member States: France, Italy, Poland, Sweden and Germany as the lead nation. The planned duration of the project is 42 months with an overall budget of around €31 million (excl. VAT).

The ERA industrial consortium is led by Airbus Defence and Space, and composed of sixteen partners from five EDA Member States: Airbus Defence and Space and ESG Elektronik system- und Logistik-GmbH from Germany; Sagem, Thales and ONERA from France; Saab from Sweden; Finmeccanica from Italy; and nine partners from Poland: Air Force Institute of Technology (leadership Polish consortium), Institute of Aviation, Hertz Systems Ltd., EUROTECH, PIAP (Przemysłowy Instytut Automatyki i Pomiarów), Eskadra Grzegorz Trzeciak, Politechnika Rzeszowska (Rzeszow University of Technology – RUT), WB Electronics S.A., Asseco Poland S.A.

AGILE

Date: 2015.06.01 - 2018.11.30

Current aircraft development programs are performed as collaborative and multi-organisational design processes. The main challenge that hampers cost-effective design processes is the integration of multidisciplinary competences and services provided by heterogeneous teams with different skill sets, which are distributed among different organisations and across different nations. Therefore, the key-enabler to deliver innovative aircraft products in a time and cost-efficient manner is the development of a "more competitive supply chain".

The AGILE project, which is granted by the European Commission, brings together 19 industry, research and academic partners from nine countries to address the complex challenge of collaborative product development. The project aims to achieve the reduction of 20% in time to converge the design of an aircraft and a 40% time needed to set up and solve the multidisciplinary problem in a team of heterogeneous specialists. Therefore, the overall AGILE project objective is to achieve a significant reduction in aircraft development costs through a more competitive supply chain able to reduce the time to market of innovative aircraft products.

The scope of the project comprises the following technical objectives:

- The development of advanced MDO (Multidisciplinary Design and Optimisation) techniques, and effective setup and integration methodologies in the design process reducing the convergence time in aircraft optimisation.
- The development of processes and techniques for efficient multisite collaboration in overall aircraft design teams.
- The development of knowledge enabled information technologies to support interdisciplinary design task by processes formalisation and automation.
- Developing and publishing an open MDO test suite to deploy the AGILE Paradigm.

The composition of the AGILE consortium reflects the heterogeneous structure characteristic for today's aircraft development teams and virtual supply chains: including airframe OEMs, suppliers, as well as specialist design teams. The AGILE methodologies are currently adopted to investigate several designs and optimization scenarios and will be deployed during the rest of the project to design unconventional aircraft configurations.

CAPPADOCIA

Date: 2013.10.01 - 2017.09.30

The mission of the Advisory Council for Aeronautics Research in Europe (ACARE) is to provide the European Commission with strategic orientations for the future of European aeronautical research. The Strategic Research Innovation Agenda (SRIA), ACARE's roadmap, has thus contributed to the definition of the European Commission's policies in this area. In 2011, the

European Commission published a report entitled "FlightPath2050", which presents Europe's vision for aviation. In particular, it specifies the future major challenges of research and innovation in this sector.

Within this context, CAPPADOCIA (Coordination Action Pro "Production, Avionics, Design" on Cost-efficiency in Aeronautics) is a Coordination and Support Action (CSA), which is focused on research activities that address solely or mainly the SRIA goal of cost-efficiency in Aeronautics and Air Transport and in particular the following technical domains:

- Airframe design systems and tools
- Production and maintenance
- Avionics and other relevant domains dealing with cost efficiency, e.g. propulsion

The CAPPADOCIA project is composed of ten partners and funded by the European Commission under the 7th Framework Program. Its mission is mainly to provide strategic recommendations for better coordination of research and innovation policies in the aeronautical sector.

CAPPADOCIA assesses how the achievement of SRIA objectives impacts cost optimization, in the cost-efficiency sense, of the aerospace value chain (design, avionics, system, production, maintenance). Each year, a state of the art developed by CAPPADOCIA identifies "key" scientific and technical barriers, those technological areas that have not been enough worked on and new opportunities for innovation. These results are tested and eventually completed by the aviation community through experts' interviews and dedicated workshops.

Then, CAPPADOCIA consolidates its analysis in an annual report, formalizes its strategic recommendations and proposes it to all the industry through ACARE and, more broadly, to the aviation community via the European Commission.

EBSF_2 – EUROPEAN BUS SYSTEM OF THE FUTURE 2

Duration: May 2015 – April 2018

The "Bus System of the Future" projects (EBSF and EBSF_2) aim to develop a new generation of urban bus systems. The aim is to develop and deploy innovative vehicle technologies and infrastructures integrating the best operating practice and which have been tested in operations scenarios in several bus networks in Europe.

The EBSF, coordinated by U*nion internationale des transports publics (*UITP), combines the efforts of 42 partners. The joint collaboration of industries, operators and authorities allows testing and evaluating a set of technological solutions for improved efficiency of urban and suburban bus systems as well as attractiveness to the users. Part of the experiment was presented on 30 March 2018 by RATP Group, the CEA and Iveco Bus. They presented a demonstration of a fully autonomous bus depot in the level 3 basement of the Lagny bus centre in the 20th arrondissement in Paris.

The outstanding results come from RATP Group which teamed up with two partners, IVECO BUS and CEA List, to develop the automation system for depot operations and conduct the demonstration:

- **IVECO BUS** modified one of its electric hybrid Urbanway vehicles operated by RATP with approval from Ile-de-France Mobilités to be driven electrically and steered autonomously.
- **CEA List** also deployed its expertise in artificial intelligence and robotics. The bus is equipped with sensors and an autonomous navigation controller, which makes it capable of locating and steering itself without human intervention while detecting any obstacles.
- Teams at **RATP Group** steered the overall project, integrated various sub-systems and developed the interface between the bus and the current fleet management systems to tell the bus about available spaces in the depot. RATP Group also oversaw demonstration safety.

KEY TOPIC T3.3 – MAPPING PATENTS IN AVIATION TECHNOLOGIES

Introduction and Short Background Literature for Aviation Technologies

According to IATA records first scheduled commercial airline flight took place from St. Petersburg, FL to Tampa, FL on January 1914. Beginning with national flights, international flights came forward and long-range flights have taken place in a decade by KLM in 1924. And now, 4 million people scheduled and 58.2 million freight transported with a revenue of 743 billion in 2017. However, there are many challenges for the aviation industry, especially from the environmental side. The amount of greenhouse gases generated by the aviation industry accounts for about 3% of the total generated amount in the world. Moreover, because the greenhouse gases are exhausted in high-altitude areas trees and plants cannot absorb it as in road-related greenhouse gases. Therefore, the aforementioned 3% becomes 13% of the overall greenhouse effect by the aviation industry.

Now, the dilemma is coming for the aviation industry with increasing demand on passenger traffic and the environmental goals of the next few decades. Based on the study of Kellari et al. (2017) general domains of study in aviation technology includes "*the optimization of existing aircraft architectures for maximizing aircraft performance or minimizing environmental impact; examining potential future architectures which have superior performance over the current dominant design; and, extrapolating performance trends in order to predict future aircraft performance.*"

Optimization studies are mostly aimed to minimize fuel burn, emissions or noise, or operating costs. Multidisciplinary design optimization is generally used in this field for optimization. Kellari et al. (2017) mentioned some technological advancements as blended-wing body or flying wing architecture; "double-bubble" and "hybrid wing body" architecture of NASA. According to the author, engine architecture is a major driver for aircraft architecture. Bypass ratio, increasing individual component efficiency, and increasing turbine inlet temperature along with increasing overall pressure ratio are the study trends on engine improvement field.

However, there are technical constraints regarding material thermal properties, emission regulations, aerodynamic issues and geometric constraints of the dominant architecture.

There are a few scholarly works in accordance with the technological analysis of aviation technology. One of them is Nakamura et al. (2012)'s study, which is aimed to map aerospace engineering comparatively with citation network analysis by using patent data of aerospace industry and Toyota. They found that in system level there are similar technology fields for improvement in both aviation and Toyota. In another study, Kwon and Lee (2012) prepared a technology forecast for sustainable (green) aviation by using patent analysis. Based on the study findings, it is asserted that technology developments for fuel cell and noise area in the green aviation technology area were continuously performed in the 2000s. Finally, they forecasted that new aircraft engines would be expected to be focused on for development as a new technology for future green aviation.

Data and Methodology in Brief

Patents, as a vital data source, are the main outputs of research and development that represent the characteristics of technology. A vast amount of recent technical knowledge is available in patent documents and the importance of exploiting this knowledge has been constantly increasing since electronic patent database is accessible worldwide (Ernst, 2003). Hence, patent data have been considered as an important source in technology evaluation and analysis research.

Patent analyses have been used to assess the knowledge diffusion and transfer processes in research and development which extract useful knowledge from databases. There are, of course, classification on using patent data as indicators of technological analysis (Karki, 1997). Patent analysis can be divided into macro-level research of national or industrial analysis (Curran & Leker, 2011) and micro-level research of particular technological diffusion analysis (Lee, Kim, & Cho, 2010) and forecasting (Chang et al., 2009). In the macro level, the major topics are technological innovation and evaluation of technological competitiveness of nations. In the micro-level, research activities, such as identifying technological advantages and disadvantages of competitors.

The patent analysis method has been used at length to understand the invention and innovation processes. There are a number of different uses patent data such as the analysis of the time-lag between the allocation of research funds and patents issues (Daim et al, 2006); to assess innovation diffusion (Nelson, 2009); or predicting the future directions of technological development (Choi et al., 2011). There were two accepted perspectives in patent technology analysis; citation-based and content-based approaches. Citation-based studies consider the citations between two patents as knowledge flows (Gress, 2010). By using these knowledge flows main technological trends may be discovered. However, these visualizations neglected the patent contents and the quality of the citation relationship cannot be recognized. On the other hand, content-based studies used text-mining techniques to measure the content similarity between pairs. Another alternative approach is a network-based patent analysis which prepared for overcoming drawbacks of citation analysis. Although network analysis shares some commonality with citation analysis, its relative advantage is substantial. First, network analysis shows the relationship among patents as a visual network and therefore assists the analyser in intuitively comprehending the overall structure of a patent database.

Second, network analysis enriches the potential utility of patent analysis because it takes more diverse keywords into account and produces more meaningful indicators (Yoon & Park, 2004). Network analysis based on text mining which decreases search time and cost. Therefore, it can be said that by applying network analysis approach content-based studies and citation-based studies are combined. A general patent analysis scenario may be demonstrated as in Figure 3.5:

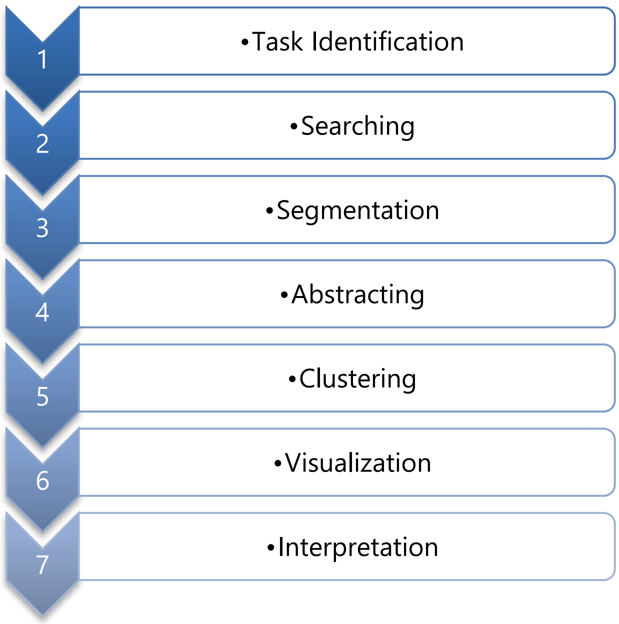

Figure 3.5 - Typical Patent Analysis Steps

As can be seen in Figure 3.5 typical patent analysis steps begins with defining the scope, concepts, and purposes of the analysis. The second issue is deciding the search query strategy. After searching and downloading the related patents data should be segmented, cleaned and normalized. In the fourth step, patent content should be analysed to summarize their claims, topics, functions, or technologies. By clustering in the fifth step analysed patents grouped or classified based on some used metrics. These groups are visualized in the sixth step and then technology or business trends and relations predicted at the last step. As can be seen, this scenario requires the analyst to have a certain degree of expertise in information retrieval, domain-specific technologies, and business intelligence. This multi-discipline requirement makes such analysts hard to find or costly to train. Therefore, automated technologies for assisting analysts in patent processing and analysis are thus in great demand (Tseng, Lin & Lin, 2007).

The patent analysis in the current study was performed with the use of the Vantage Point software (Watts *et al.*, 1997). Derwent Innovations Index is used as a data source. In Derwent Innovations Index, patents are divided into 20 broad subject areas or sections. These sections are grouped into three areas as; Chemical Sections (A - M), Engineering Sections (P - Q), Electrical and Electronic Sections (S - X). These sections are then further subdivided into classes. Each class consists of the section letter, followed by two digits. For example, X22 is the class designation for Automotive Electrics and C04 is the class for all Chemical Fertilizers.

The used search term is 'aviation' in the Topic field of patents and reached 23,508 patents. Because this study is configured as explanatory, filters are not applied to limit the data corpus at first. Data retrieved from the database and then cleaned for further analysis. Some pre-specified thesaurus and fuzzy clustering algorithms applied in this stage.

Findings

Trends of Patents on Aviation

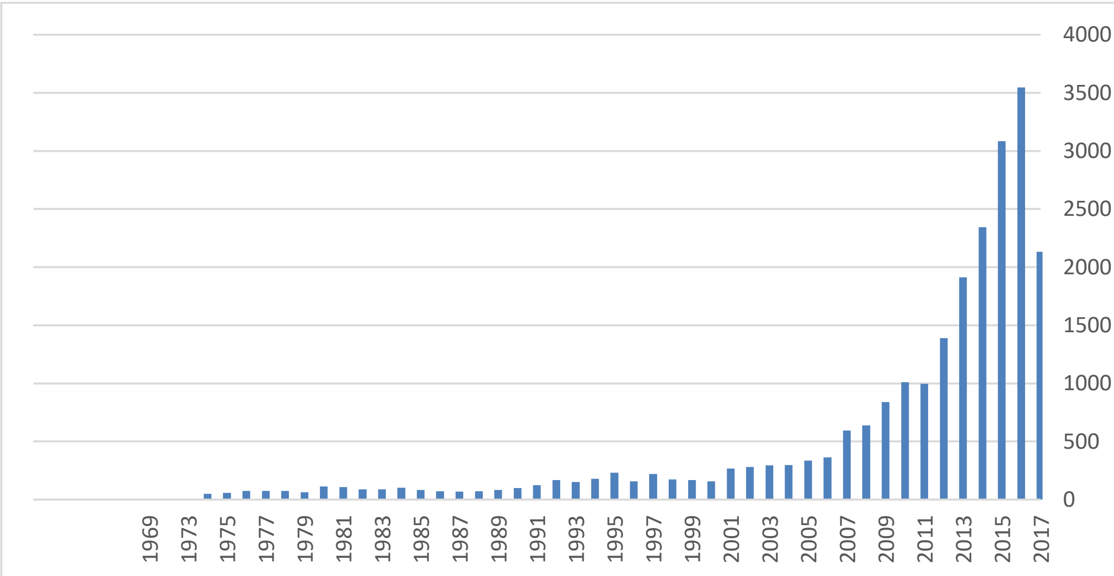

Figure 3.6 – Number of patents in aviation per year

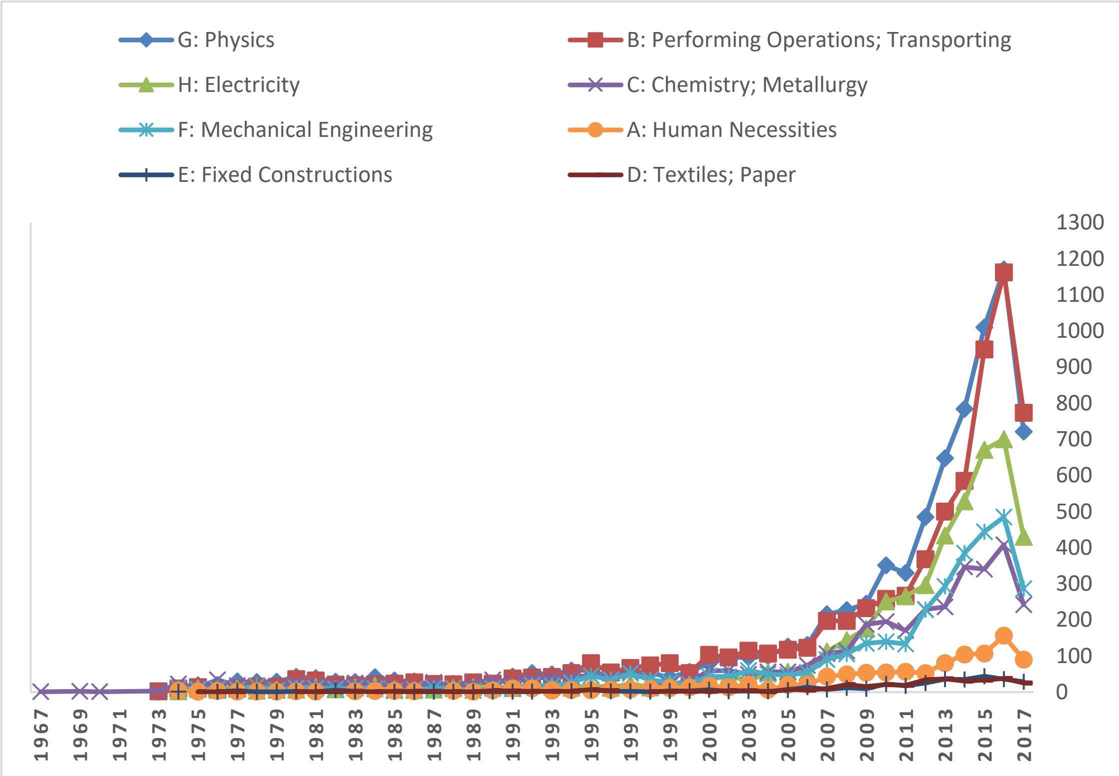

Figure 3.7 IPC subclasses year chart

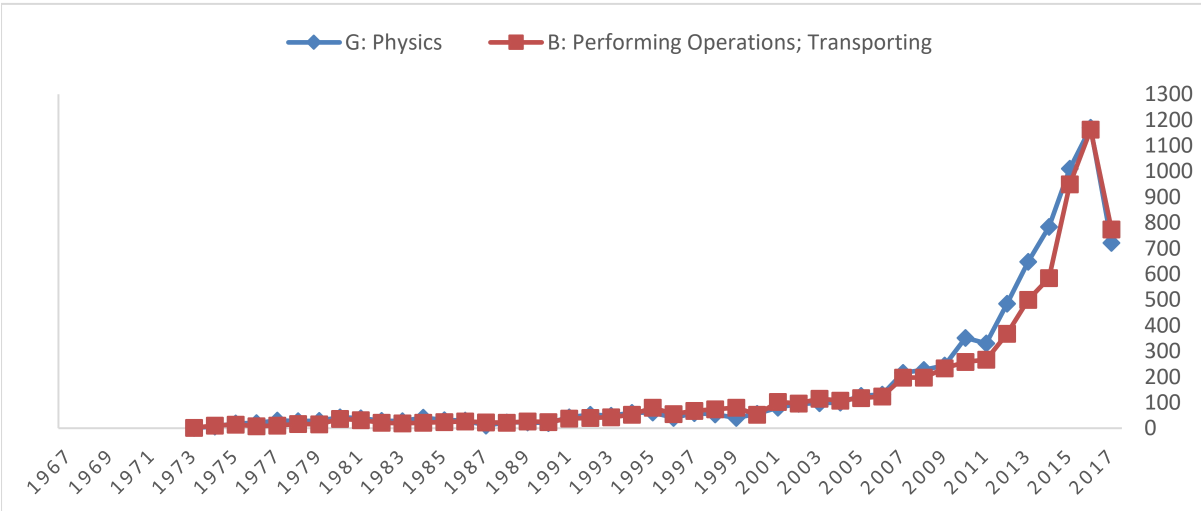

Figure 3.8 - Macro Classes

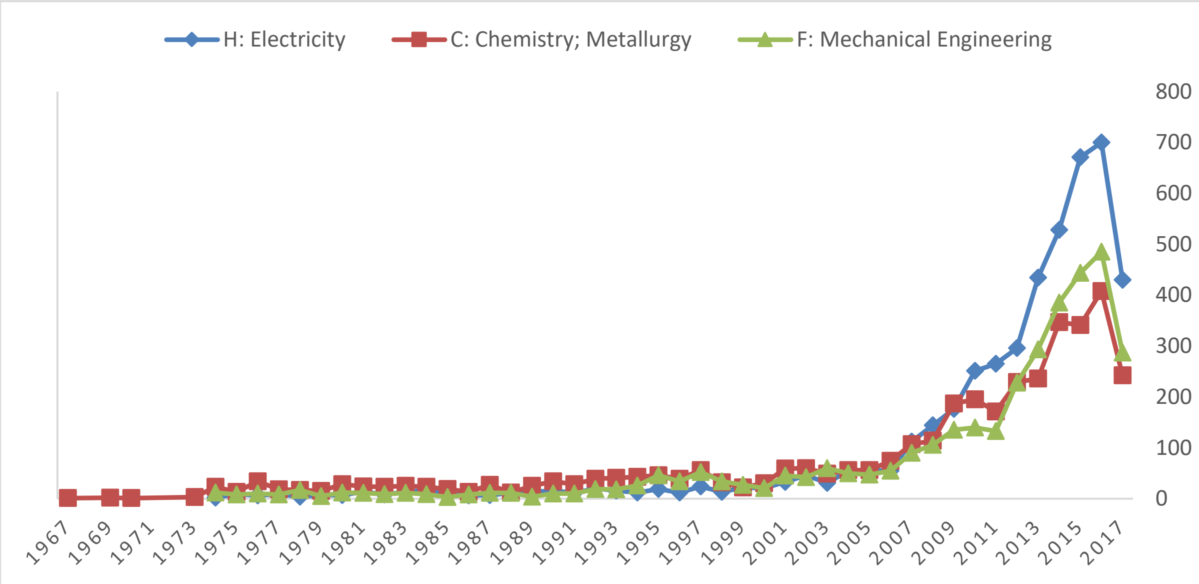

Figure 3.9 – Medium Classes

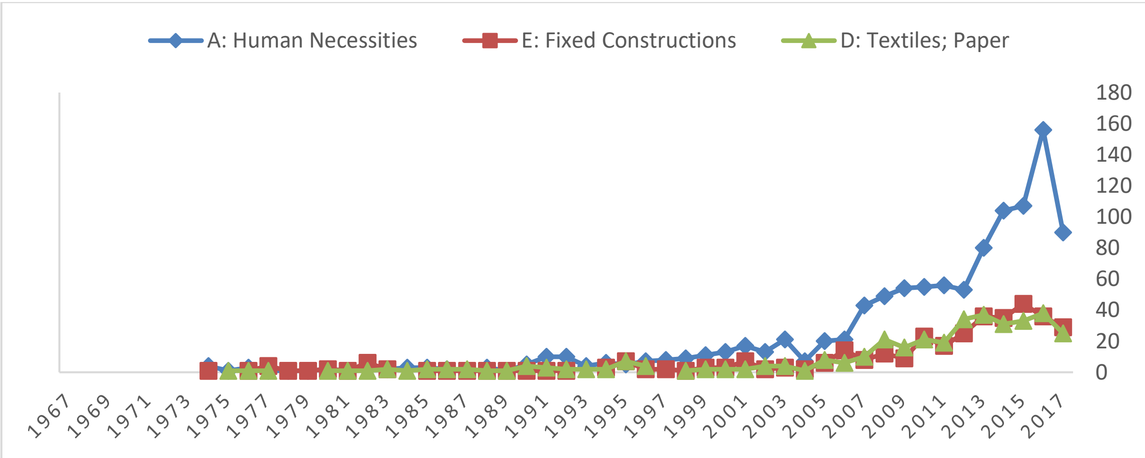

Figure 3.10 - Micro Classes

Sunburst Diagram for General and a, b, c, d, e, f, g, h Subclasses

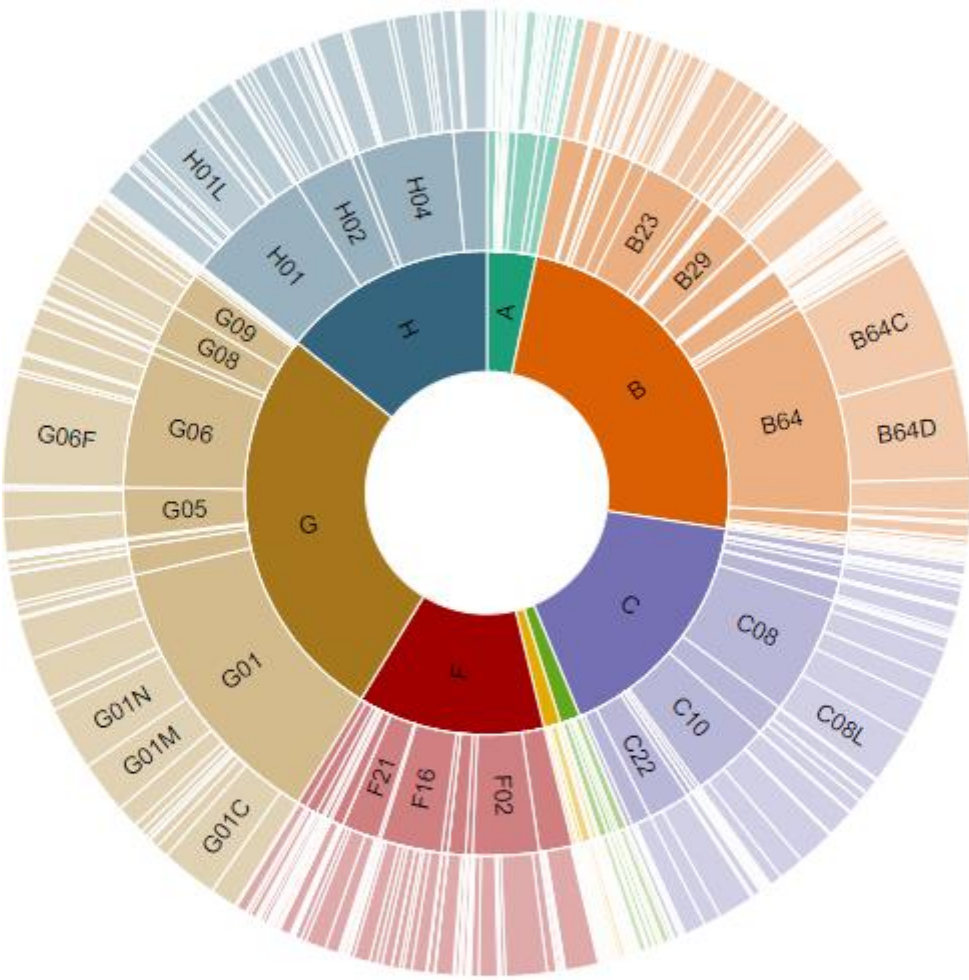

Figure 3.11 Sunburst diagram for general and a, b, c, d, e, f, g, h subclasses

Code	%	Definition
G	27,3	Physics
B	24,9	Performing Operations; transporting
H	16,2	Electricity
C	13,1	Chemistry; Metallurgy
F	12,2	Mechanical Engineering lighting; Heating; Weapons; Blasting
A	3,7	Human Necessities
E	1,3	Fixed Constructions
D	1,3	Textiles; Paper

Table 3.2 – Some patent codes

Code	%	Definition
G01	12,7	Measuring; Testing
B64	9,3	Aircraft; Aviation; Cosmonautics
H01	6,2	Basic Electric Elements
G06	6,2	Computing; Calculating; Counting
H04	4,0	Electric Communication Technique
C08	3,1	Organic Macromolecular Compounds; Their Preparation Or Chemical Working-Up; Compositions Based Thereon
C10	3,1	Petroleum, Gas Or Coke Industries; Technical Gases Containing Carbon Monoxide; Fuels; Lubricants; Peat
F16	2,9	Engineering Elements Or Units; General Measures For Producing And Maintaining Effective Functioning Of Machines Or Installations; Thermal Insulation In General
F02	2,9	Combustion Engines; Hot-Gas Or Combustion-Product Engine Plants
H02	2,8	Generation, Conversion, Or Distribution Of Electric Power
B23	2,6	Machine Tools; Metal-Working Not Otherwise Provided For
G05	2,5	Controlling; Regulating
G08	2,0	Signalling
G09	1,9	Educating; Cryptography; Display; Advertising; Seals
C22	1,7	Metallurgy; Ferrous Or Non-Ferrous Alloys; Treatment Of Alloys Or Non-Ferrous Metals

Table 3.3 – Some patent subcodes

Code	%	Definition
B64C	4,1	Aeroplanes; Helicopters
B64D	3,7	Equipment For Fitting In Or To Aircraft; Flying Suits; Parachutes; Arrangements Or Mounting Of Power Plants Or Propulsion Transmissions
G06F	3,7	Electric Digital Data Processing
G01N	2,2	Investigating Or Analysing Materials By Determining Their Chemical Or Physical Properties
G01C	1,9	Measuring Distances, Levels Or Bearings; Surveying; Navigation; Gyroscopic Instruments; Photogrammetry Or Videogrammetry
G01M	1,8	Testing Static Or Dynamic Balance Of Machines Or Structures; Testing Structures Or Apparatus Not Otherwise Provided For
C08L	1,7	Compositions Of Macromolecular Compounds
H01L	1,7	Semiconductor Devices; Electric Solid State Devices Not Otherwise Provided For
G01R	1,4	Measuring Electric Variables; Measuring Magnetic Variables
B32B	1,4	Layered Products, I.E. Products Built-Up Of Strata Of Flat Or Non-Flat, E.G. Cellular Or Honeycomb, Form

Table 3.4 – Some patent sub-subcodes

Country Evaluations

Basic Patent Country	Patent Number
China	11876
United States of America	3249
Russian Federation	2140
Soviet Union (USSR)	1393
World Intellectual Property Organization (WIPO)	1327
Korea (South)	1308
European Patent Office	637
Germany	369
France	305
Japan	254
United Kingdom	191
India	98
Canada	56
Brazil	37
Australia	28
Belgium	28
Taiwan	26
Romania	19
Spain	15
Poland	14

Table 3.5 – Patent to country

- <u>World Map</u>

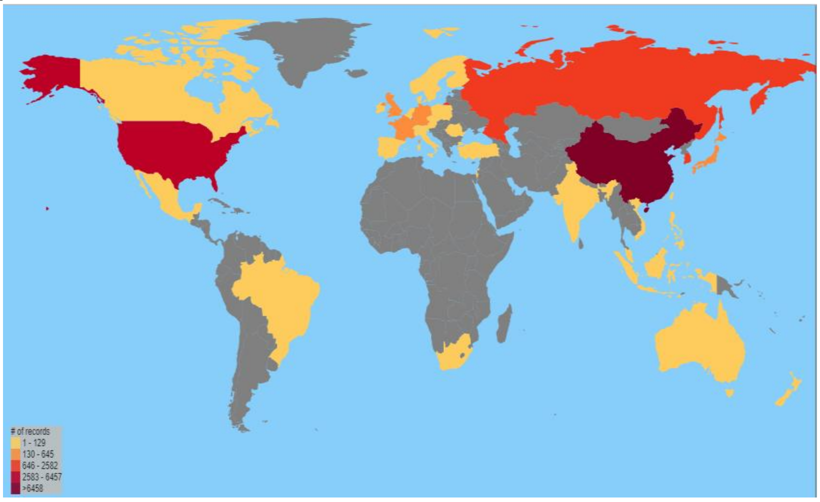

Figure 3.12 – World map distribution

➤ <u>Top 10 Country Patent Numbers Per Year</u>

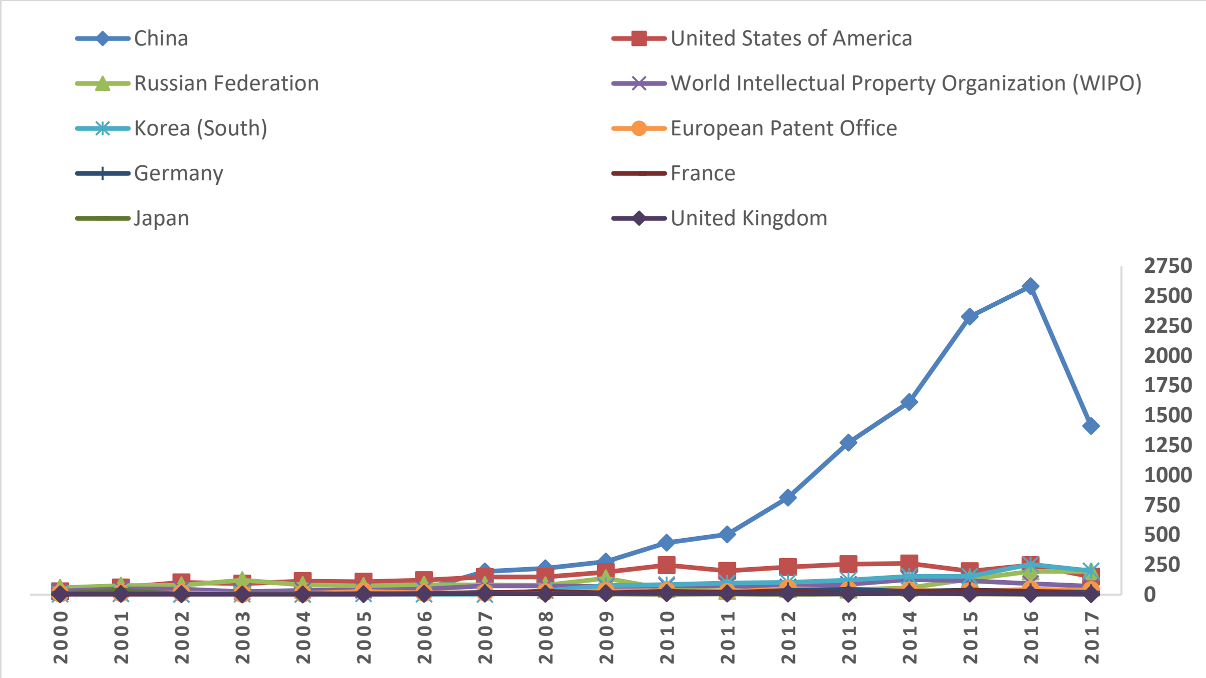

Figure 3.13 – Evolution in the number of patents

➤ <u>Top 10 Country Patent Numbers based on Subclasses Per Year</u>

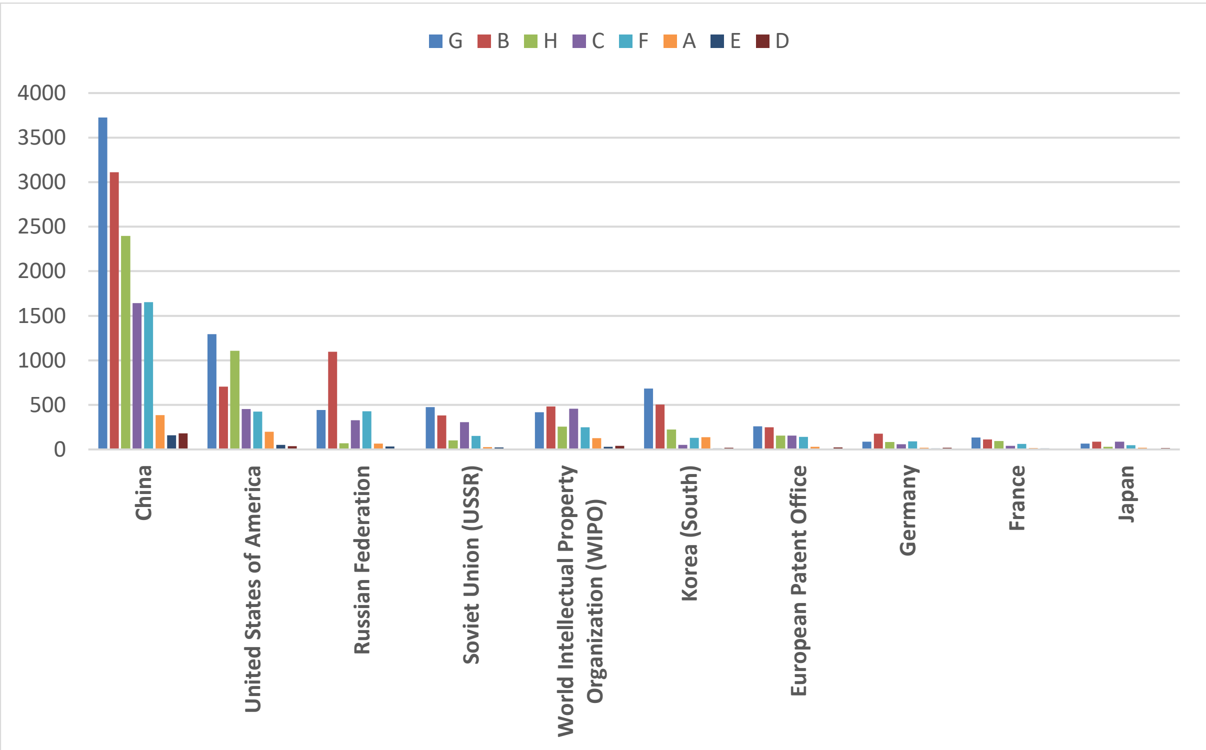

Figure 3.14 – Aviation patents per country

Patent Assignees

Patent Assignees	Record
Stats Chippac Ltd	369
Honeywell Int Inc	233
Shenyang Liming Aero Engine Group Corp	222
General Electric Co	193
Univ Beijing Aeronautics & Astronautics	189
Univ Nanjing Aeronautics & Astronautics	165
Boeing Co	151
Harbin Inst Technology	145
State Grid Corp China	142
Rockwell Collins Inc	123
Univ Beihang	106
Avic Comml Aircraft Engine Co Ltd	103
Aviation Ind Corp China Shenyang Engine	99
Stats Chippac Pte Ltd	94
Univ Northwestern Polytechnical	90
Aviation Materials Res Inst	88
Univ China Civil Aviation	83
Thales	75
Avic Shenyang Engine Design Inst	71
United Technologies Corp	71

Table 3.6 - Top Twenty Firms by patent number

- <u>Patent Numbers Per Year</u>

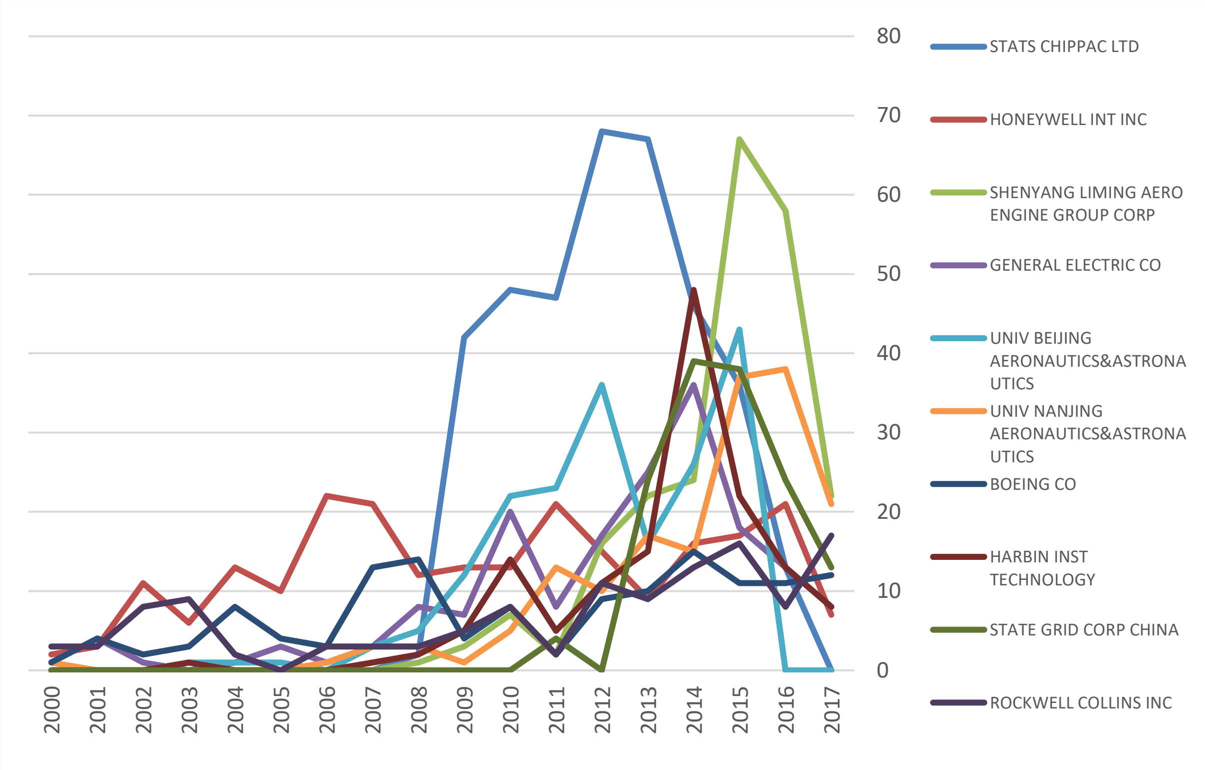

Figure 3.15 - Top Ten Firms by patent number

- <u>Patent Numbers Based on Subclasses Per Year</u>

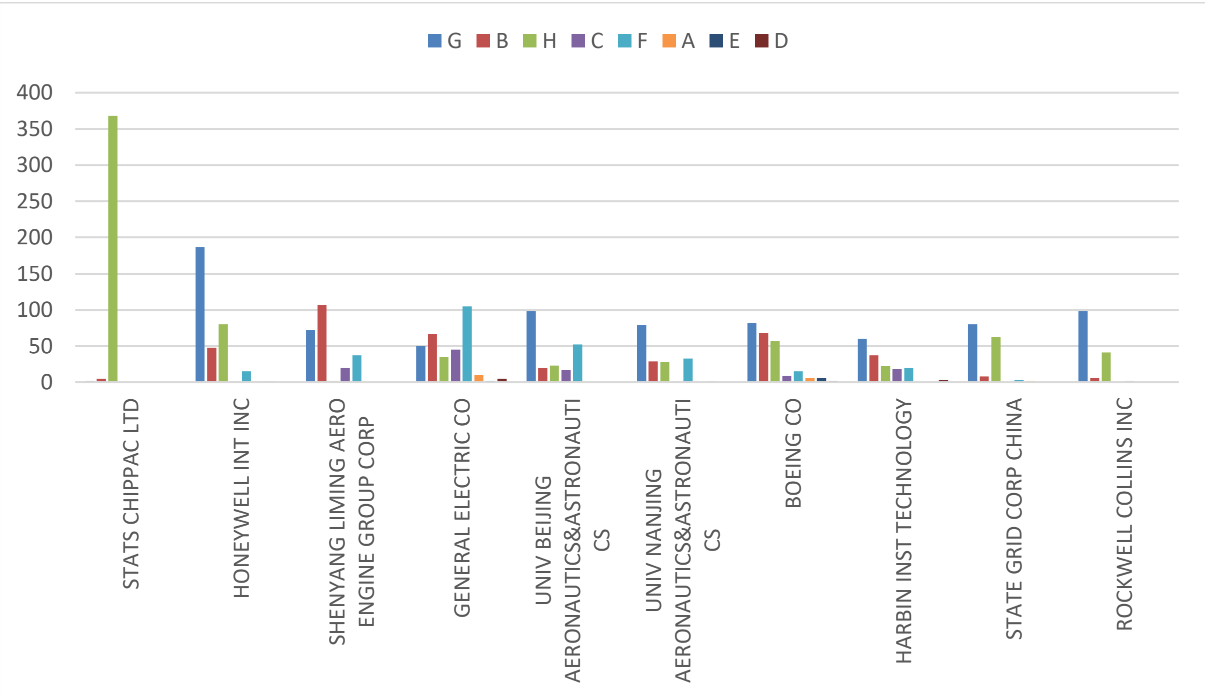

Figure 3.16 – Number of patents per holder

Title Words Analysis

➢ <u>Derwent Classification Network</u>

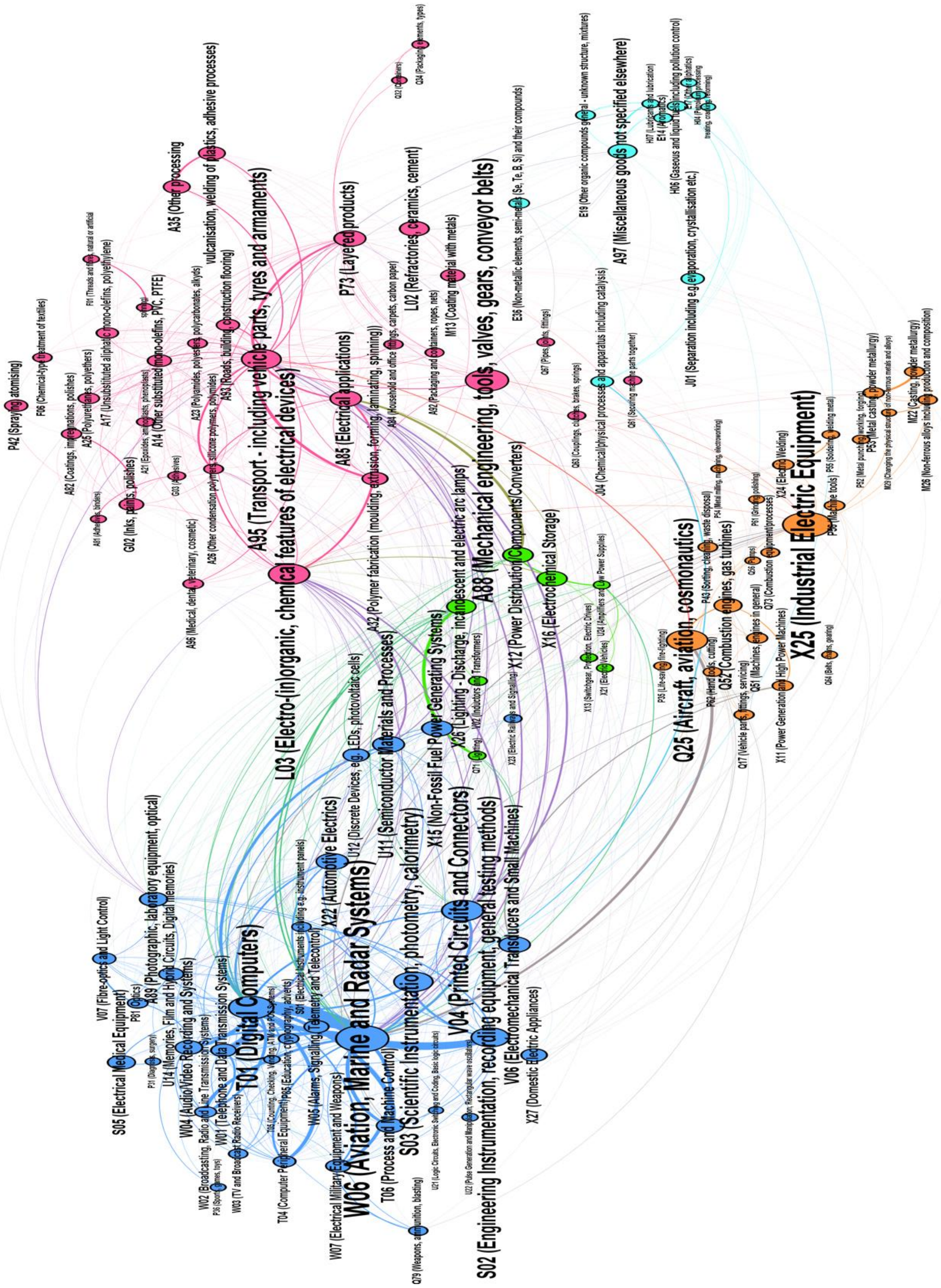

Figure 3.17 – Patents in areas relevant to aeronautics

➢ <u>Title Words Network</u>

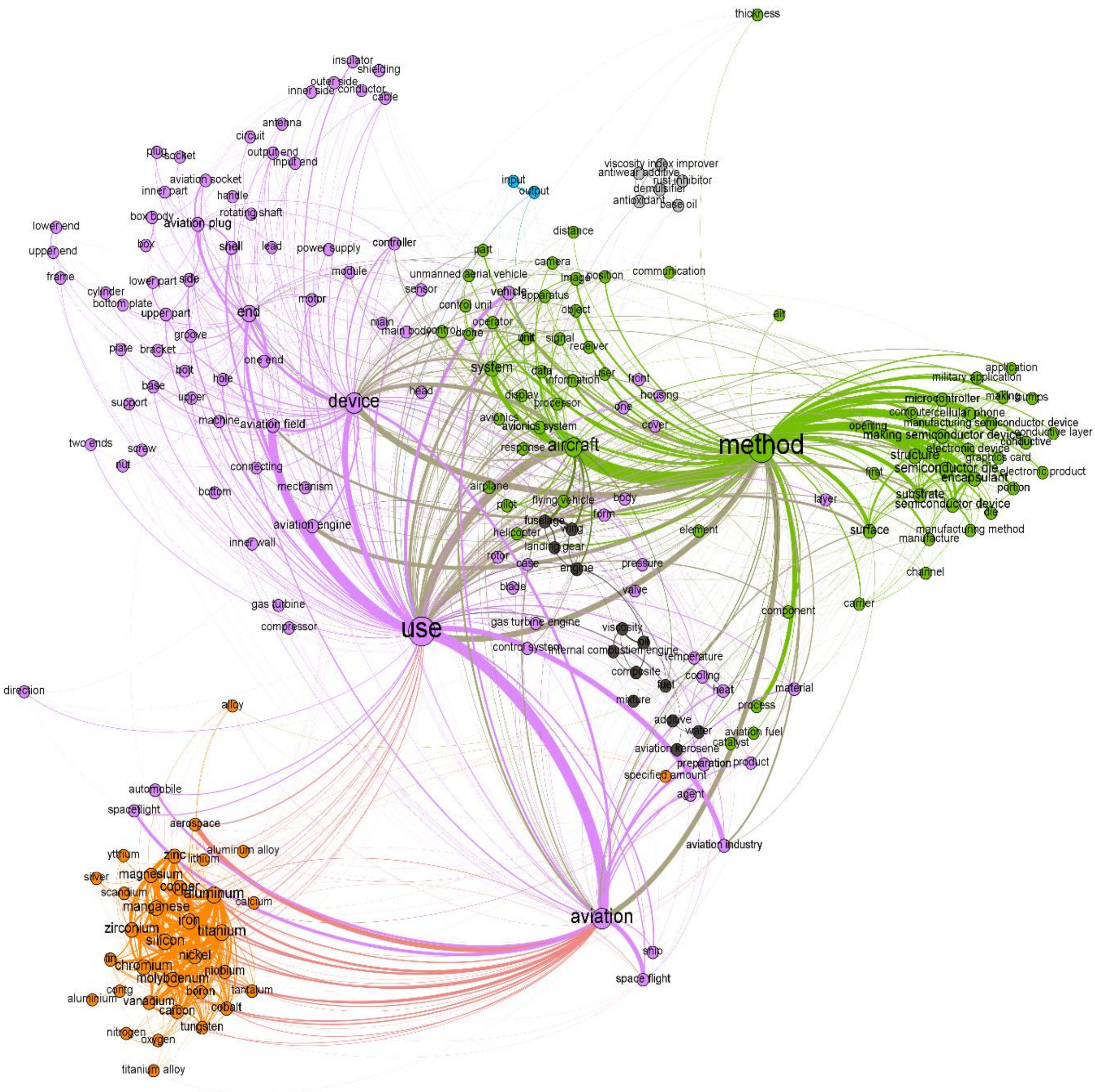

Figure 3.18 – Patents per subject

3.3 Efficient Development and Life-Cycle Management

Flightpath 2050 goal 8 "Streamlined systems engineering, design, manufacturing, certification and upgrade processes have addressed complexity and significantly decreased development costs (including a 50% reduction in the cost of certification). A leading new generation of standards is created".

It is not sufficient to master the cutting-edge of all 10 relevant aeronautical technologies (goal 7 and section 3.2) it is also necessary to integrate them into a product with timely arrival in the market and competitiveness over the whole life-cycle:

- The mature and cost-effective technologies in all 10 relevant areas must be selected and incorporated in a new high-performance design that significantly improves all existing products without an excessive development risk;

- The development program must focus on validation and verification of all new features that may involve a higher risk while making sure that lessons learned are used to improve all other items;

- The production process must be as reliable and fast as possible, allowing for unexpected modifications with minimal upset and providing a margin for product evolution;

- The certification process must be considered from the beginning of design through development and production, to minimize the risk of redesigns and costly delays, that may have a domino effect on market availability and share;

- The supply chain and final assembly capabilities need to be able to keep up with high market demand, and survive market lows without cost penalties while ensuring prompt service support in all situations;

- If the aircraft is not the first to the market it should try to claw back leadership by embodying performance-enhancing features that cannot be incorporated in the existing competitors;

- If the aircraft is the first to the market, it should anticipate the possible responses by competitors, leaving no room for alternatives that could render it outdated or uncompetitive;

- The competitiveness should be maintained by upgrades to keep the product ahead of other alternatives in performance, cost, availability and service support;

- In parallel with the gradual improvement of the existing aircraft, a whole series of clean sheet designs covering a wide range of options should be pursued, to be ready to introduce the follow-on product at the right time to keep or increase market share.

The growing capability and complexity of modern aircraft increase the relevance of life-cycle analysis (Key Topic T3.4) that needs to be considered also at the component level (Key Topic T3.5).

KEY TOPIC T3.4 – AIRLINER DEVELOPMENT TIME AND COST

Benchmarks

Current programmes did show a continuous rise in the cost of development (including certification) which is correlated with the increased complexity of the machine (frequently supported by new technologies) on one hand and the ever-larger demands for safety and lower life-cycle costs. The development time has shown a similar trend, responding to the same factors:

Aircraft	Year of First Service	Development Costs (Constant 2014 $)	Development Time in Years
Douglas DC-3	1936	4.9 Million	2
Douglas DC-6	1946	173 Million	3
Boeing 707	1958	1.5 Billion	6
Boeing 747	1970	5.8 Billion	4
Boeing 777	1995	8.0 Billion	6
Airbus A380	2007	16.5 Billion	7
Boeing 787	2012	13.6 Billion	7
Airbus A350 XWB	2014	15.6 Billion	8

Table 3.7 – Some data on recent widebodies

An important remark is that all the programmes listed above were clean sheet projects. A significant upgrade of an existing model could reduce both the costs (by a factor of 1:5 to 1:10) and the time to first delivery (by a factor of 1:1.5 to 1:3), factor depending on the quantity of the improvement targeted. As an example, data available for Airbus A320neo (first delivery 20 January 2016) show a duration of the development of 5 years and an estimated cost of $1.3 Billion.

Unfortunately, a comparative analysis of the tendency of the two measures in the Table above would not provide a correct indication of the degree of evolution because one would compare different sizes and generations of aircraft. So, the benchmark is to be created otherwise.

A simple and accessible approach is taken by P. Nolte et al in an article published by R. Curran and L. Fischer in Air Transport and Operations. Proceedings of the Third International Conference (page 525). The author takes into account the complexity by defining a Specific Development Cost (per number of model's passenger seats), SDC. Similarly, the development period might be corrected by the same parameter, resulting in the SDP – Specific Development Period. (The source mentioned here proposed one other measure, Development Cost per Seat Built, which we do not consider relevant for our purpose).

Aircraft	Number of Seats	Development Costs (Constant 2014 $ mil)	Development Time (Years)	SDC ($mil/seat)	SDP ($mil/year)
Douglas DC-3	21	4.9	2	0.2	2.5
Douglas DC-6	60	173	3	2.9	57.7
Boeing 707	145	1500	6	10.3	250.0
Boeing 747	410	5800	4	14.1	1450.0

Aircraft	Number of Seats	Development Costs (Constant 2014 $ mil)	Development Time (Years)	SDC ($mil/seat)	SDP ($mil/year)
Boeing 777	335	8000	6	23.9	1333.3
Airbus A380	545	16500	7	30.3	2357.1
Boeing 787	242	13600	7	56.2	1942.9
Airbus A350 XWB	325	15600	8	48.0	1950

Table 3.8 – Some data on legacy and current airliners

For this application, restricting the analysis to SDC and SDP is not expected to induce major errors. However, for a future increase of accuracy, other factors as service life, life cycle costs etc. should be considered.

- Aircraft development costs, prices, times, total income, break even number

The total operating cost (TOC) include the direct operating costs (DOC) and indirect operating cost (IOC). The DOC includes the cost of ownership (e.g. depreciation, interest, insurance) as well as flight costs such as cockpit crew, cabin crew, fuel and fees. The IOC includes the other maintenance cost such as airframe and engine, even if certain cost elements normally included in DOC, such as cabin crew cost are considered to be IOC.

However, in aircraft new technologies and aircraft designs assessment the DOC plays a key role, alternatively, lifecycle-based models can be used. However, even if less common, probably due to the more detailed information requires, the usage of life cycle-based models provide an enhanced breakdown of the economic impact.

Newer engines and larger aircraft helped significantly in reducing the DOC, this target has been reached with the introduction of new technologies such as increased use of carbon fibre reinforced polymer and advanced sophisticated metallic alloys to reduce weight, advanced integrated aerodynamics, improved systems and so on. Figure 3.19 – shows a typical gradual increase in the contributions to the DOC of an aircraft.

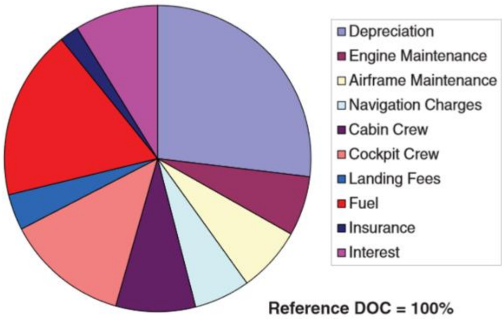

Figure 3.19 –Typical Direct Operating Cost Breakdown Fuel Price $0.8.

Another major issue and cost of aircraft design is the price of fuel. Kerosene will be the only viable fuel for passenger aircraft- due to its excellent energy density by volume and by weight. Nevertheless, in future, it will be produced from fossil oil, biomass and so on, and probably the cost will increase. Figure 3.20 – shows the cost of aviation fuel since the year 2000.

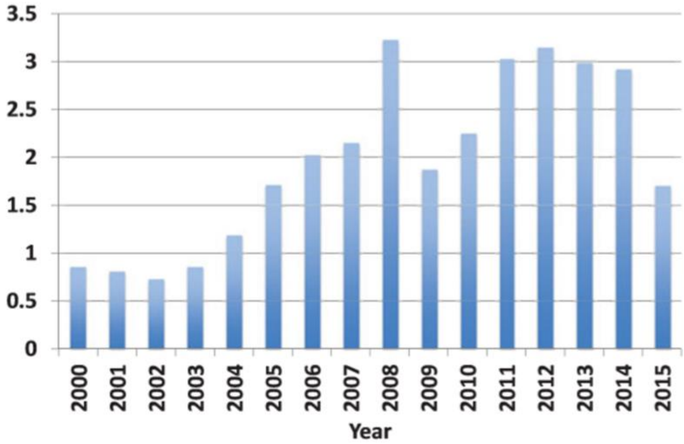

Figure 3.20 –Cost of aviation fuel since the year 2000.

It is useful to note that the Boeing 787 and the Airbus A380 were designed when the fuel price was in a period of relatively low oil prices (i.e., 2003 and 2000 respectively).

Nowadays, to ensure competitiveness and in light of increasing global competitive market, all the aviation stakeholder, have to decrease their cost and increase their revenues.

There will be both extreme economic and environmental pressure to reduce fuel consumption and even if the kerosene became viable in the necessary quantities, the cost is going to be extremely high and will not affect the pressure to reduce fuel burn. From an environmental point of view, even the production of contrail cirrus will an issue which also need to be addressed and it will also be minimised by reducing fuel consumption. Hence, more studies should be conducted to increase even the efficiency and to reduce the environmental impact of aircraft and air transport operations with the expected increasing demands in the next two to three decades. Since the year 2000, the European Union has supported research to improve civil aviation. In Figure 3.21 –.21 the ACARE targets environment are shown, for aircraft entering service in 2020 relative to those that were being delivered in 2000.

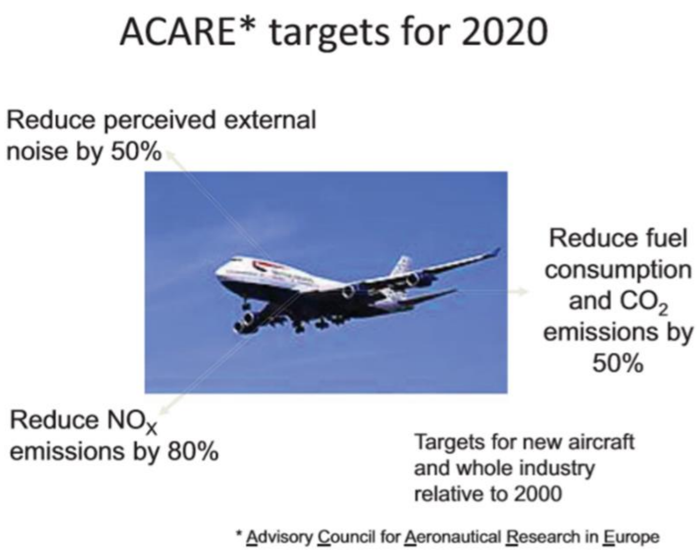

Figure 3.21 – ACARE environmental targets

Overall, we can conclude to say that the aircraft design range has a fundamental effect on fuel efficiency as discussed in the following sections.

- Operating costs, maintenance and spares revenue, support infrastructure

To produce air transport services, airlines use various tools such as labour, capital, fuel and materials. The operating cost, maintenance and spares revenue depend on different features, such as the company, the period, the needed, the concurrences, and so on. For examples, in 2014 fuel costs accounted for about 20-50% of total costs. The fuel cost is proportional to the distance of the route and differ from one country to another. Some airlines are keen to use more fuel-efficient aircraft to save costs by leasing or purchasing new aircraft. Other airlines choose to replace with newer versions of the aeroplane's interior such as the seats, television monitors, beverage carts, and so on. However, when the oil price is at a high level, these "secondary" measures may not be sufficient for airlines to retain profitability. Therefore, to reduce their exposure to volatile and potentially rising fuel cost, different companies have been used fuel hedging contracts.

Finally, the differences in aircraft capital costs (i.e. input in aircraft and ground property and equipment) across airlines largely reflect the differences in their fleet composition. Moreover, the purchased materials and services are a catchall expense category as it includes all the inputs other than labour, fuel and capital inputs.

An airline's maintenance cost is closely related to the airline's average aircraft age, as the older aircraft needs more frequent and expensive heavy checks. However, some authors found that airlines using newer aircraft have higher average operating costs per aircraft movement, which suggests that ownership costs due to depreciation and leasing cost of new aircraft outweigh the increasing maintenance cost of old aircraft. Other costs to consider are the airline cost per seats which declines with the size of aircraft and when the load factor is achieved, since much of a flight's cost is fixed regardless of the number of passengers flown.

- Flight hours and time for certification and costs of upgraded versions of aircraft

Flight hours, time for certification, and costs of upgraded versions of aircraft depend on different features as well, such as the distance, the airline need, the new technology used or design project, the urgent needed to reduce the environmental impact, and so on. For example, for an intercontinental travel duration such as between Tokyo and Washington, D.C., a commercial airliner takes approximately 12 hours in the cruise phase at an approximate cruise flight speed of Mach 0.85.

A new promising technology to be upgraded version of aircraft is the hybrid laminar flow control (HLFC) which- by reducing the aircraft drag- offers significant potential for increasing aircraft fuel efficiency and hence reducing operation costs. In this regard, interesting to note, LYFE (Lifecycle Cash Flow Environment) -a life cycle cost-benefit tool - which is a modular simulation environment developed by German Aerospace Center (DLR) for the simulation of a virtual life cycle, hence the impact of changes in the aircraft's life from manufacturing until end of life. In recent work, the authors analysed the efficiency of different DOC methods compared to the LYFE model. Their results show that the DOC methods are no so efficiently to measure the impact of the technologies even if are easier and faster. In contrast, LYFE requires more detailed input but provides key performance indicators such as the net present value or the internal rate of return, which the most used metrics in investment is budgeting. In light of this, as in aviation DOC's methods are widely used and established, due to their rather faster and easier application, it is important to give more attention to the products lifecycle.

In fact, product lifecycle management (PML) is a concept that facilitates the manufacturing planning process of new products as well as production development. All the stages are integrated and digitally processed thanks to the support of software tools. The LYFE models developed by DLR were already discussed. Recently, the Cranfield University's Aircraft Design Group developed another multidisciplinary design analysis and optimization environment named GENUS, which boats to be modular, expandable, flexible, independent, sustainable, and performable. The authors of this project, in a recent study, discussed and developed this GENUS environment to the methodologies appropriate to supersonic business jets (SSBJs) which is considered as the pioneer of the next generation of supersonic airliners. Figure 3.22 – .22 shows the position of Genus in diverse aircraft conceptual design.

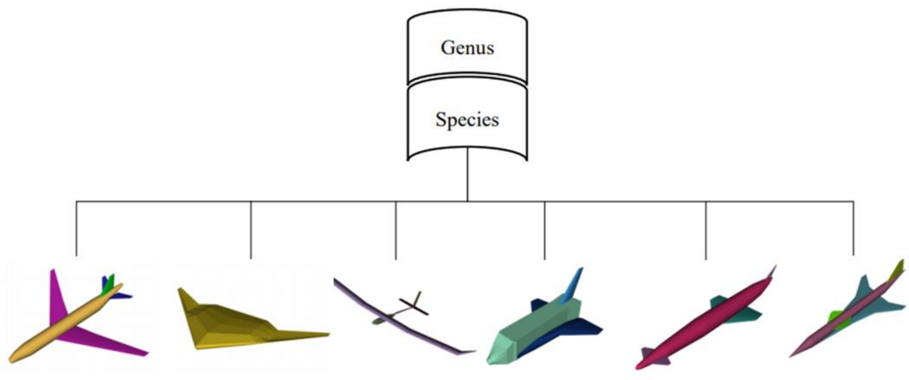

Figure 3.22 – Position of Genus in diverse aircraft conceptual design.

GENUS Aircraft Conceptual Design environment aims to achieve a flexible framework for a researcher to develop new methods for an aerospace vehicle design and less expensive. The design of a Supersonic Jet (E5 Neutrino) was carried out by a group of 30 students in Aerospace Vehicle Design at Cranfield University. The MSc students worked in synergy on this goal for seven months using almost all the requirements and attributes to a supersonic jet, such as safety, security, comfort or performance. As shown in Figure 3.23, the E5 supersonic Jet present features such as highly swept wing and thin aerofoil in order to decrease supersonic wave drag. The slender fuselage helps to mitigate sonic boom intensity and the canard generates additional vortex lift especially on a high angle of attack.

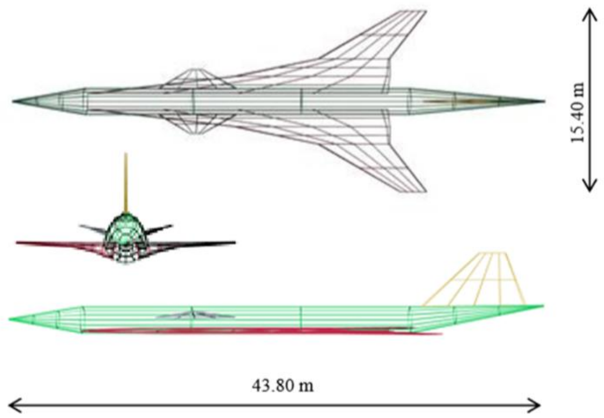

Figure 3.23 Three view design of the E5 Neutrino Supersonic Jet.

Overall, despite the efforts of these brilliant students that have been made on GENUS aircraft conceptual design environment, in future growth the need to explore more in detail some aspects such as different fidelity methods, more new engine model including hybrid propulsion system, and more stability analysis and control means setting are important challenges to be achieve.

Nowadays the airports have witnessed exponential growth, and the associated risks are congestion, delays and dissatisfied passengers. To avoid this problem, different models and methods are proposed by researchers for optimal flight paths and route. A summary is present in Table 3.9.

Research	Model/method	Objective	Result/finding/achievement
Bertsimas et al.[25]	Proposed an integer programming model covering all the phases of each flight	For optimal flow management actions	The computing times were reasonably short for large-scale problems
Choi et al.[26,27]	Compared MILP, MILP with FCFS based heuristics and MILP with heuristics of GAs	For design of optimal route structures	GA was better than MILP in terms of computational time and was more efficient than an FCFS algorithm
Li et al.[28]	Proposed a model for a liberalizing airline market	To optimize the allocation of additional routes	Flight frequencies were increased and full liberalization would bring more gains
Long et al.[29]	Utilized two metrics for ranking the choke points and measured the impact of relieving each major choke point	To evaluate NAS choke points for 2012, 2020, 2030 and 2040	The NAS would become increasingly choked, and the choke points would continue to be dominated by the airports
Alcabin et al.[30]	Surveyed 18 aviation stakeholders for understanding their views about choke points and causes	To rank the choke points in the NAS	The large hub airports had top-ranked choke points, which would account for the largest share of NAS congestion
Chen et al.[31]	Analysed the network structure of the proposed design and applied the complex network theory	For automated conflict detection and resolution	The main advantage was enhanced in-depth understanding and holistic view for control and design
Zúñiga et al.[32]	Presented a discrete event model and conducted a case study for 20 arrival flights	For conflict detection and resolution	Two trajectories were proved to be flyable
Ruiz et al.[33]	Presented a 4D-trajectories based conflict detection and resolution method	To resolve conflicts in a TMA	Validated the resulting conflict-free trajectories using a certified flight simulator and real FMS avionics
Taylor et al.[34]	Proposed an operational concept	To improve high-density-area arrivals and departures	The concept more efficiently used resources and reduced the workload of decision makers

MILP: mixed-integer linear programming; FCFS: first come first serve; GA: genetic algorithm; 4D: four-dimensional; NAS: national airspace system; TMA: terminal manoeuvring area; FMS: flight management system.

Table 3.9 - Summary of new models & methods proposed by researcher's for optimal flight paths & route.

In terms of environmental performance and noise, one of the most efficient large turbofan aero engine is the Trent XWB (Figure 3.24). Many of Rolls-Royce products are currently market leaders. Their efforts, research and development programmes aim to ensure that their future products are cleaner, quieter and more efficient.

Airbus A350-1000

Trent XWB-97 powered Airbus A350-1000 delivery to Qatar Airways

Figure 3.24 - Airbus A350. Source: www.rolls-royce.com

The aerospace sector challenges, as we have seen before, are to increase aircraft efficiency and to decrease carbon emissions, new security criteria, cost constraints and the potential negative influence of noise. Apart from GENUS project in the UK, in Europe, the SIMBA project brought together private and academic partners to develop and improve state-of-the-art tools and skills related to high-performance computer modelling. This project adapted the aerospace sector's advanced 3D-computer simulation tools and numerical methods. Their simulation tools and approach, help the designer to improve aerodynamic performance, limiting cost and time of the different design steps. Moreover, this method allows engineers to visualise the results of replacing sharp edges with another surface to achieve a better aerodynamic profile, such as better adapted in case of wind damage and so on. Once fine-tuned, the wind tunnel test and the new computer simulation tools and method were promoted to the aerospace sector via industrial meeting, training and so on. The total investment for the project "SIMBA multi-physics simulations for building applications" was 986 787€. In conclusion, one of the more forward-looking projects is the E- thrust shown in Figure 3.25 -

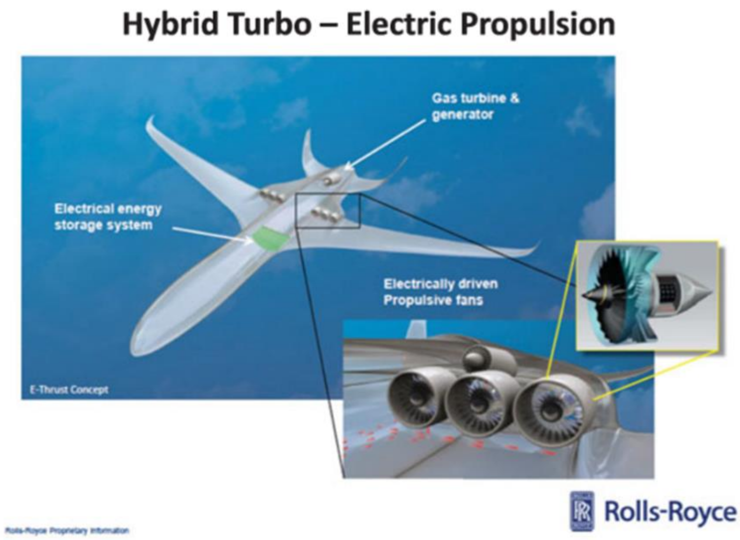

Figure 3.25 - Airbus - Rolls-Royce 'E-Thrust' project.

Progress Up to Now

The programmers started around 2000 to represent a peak in both SDC and SDP. What followed a decade later is a slight reduction in both, but much below the objective. As identified in SRIA 2017, significant reductions in the measures of aeronautical development efficiency (SDC and SDP) could be achieved by:

- Intensive use of modelling and simulation instead of physical test and experiment
- More specific, flexible and adaptive regulatory requirements (standards) for certification, including the involvement of airworthiness authority in virtual design.
- "A fully integrated multi-physics and multi-scale model of the complete aircraft including its engines and systems should be coupled with aerodynamic and thermal models, eliminating ground test rigs completely".

KEY TOPIC T3.5 – EFFICIENT DEVELOPMENT AND LIFE-CYCLE MANAGEMENT OF BATERIES

Life-Cycle Management for Secondary Batteries Possibly Used in Ground-Vehicles (e.g. towing-tractor) or Aircraft

Life Cycle Assessment of Electric Vehicles (EV)

The following consideration is related to automotive electromobility and must, of course, have been adapted to the general condition of aviation economy (e.g. ground-moving vehicles, taxiing etc.)

The environmental impacts of EVs depend on various parameters related to the vehicle's characteristics, their location of use and user influences. Variations of driving patterns of different users and the use of heating and cooling due to local climate conditions have an impact on the energy consumption of EVs. In combination with the regional electricity mix, these parameters influence the environmental impact of EVs. Therefore, the vehicles must be seen as a part of the setting with which it interacts to answer specific LCA questions. When neglecting these interdependencies, important aspects might be missed and left out. Connecting external influences with the use phase of the vehicles assist the LCA practitioner to evaluate the influence of parameters on the environmental impact. Setting up a descriptive framework allows the LCA practitioner to translate external influencing factors into environmental impacts reducing the uncertainty of LCAs.

Figure 3.26 shows the proposed framework and illustrates the EV as an element in a larger system of influencing factors and highlights the connection of energy consumption and external factors. The material and the energy flow over the entire life cycle necessary to manufacture and operate the vehicle defines the life cycle of the EV (mid-level). The setting of external factors in which the EV is deployed (top-level) influences the life cycle and the LCA results. These external factors can be divided into three groups: the user, the infrastructure and the surrounding conditions.

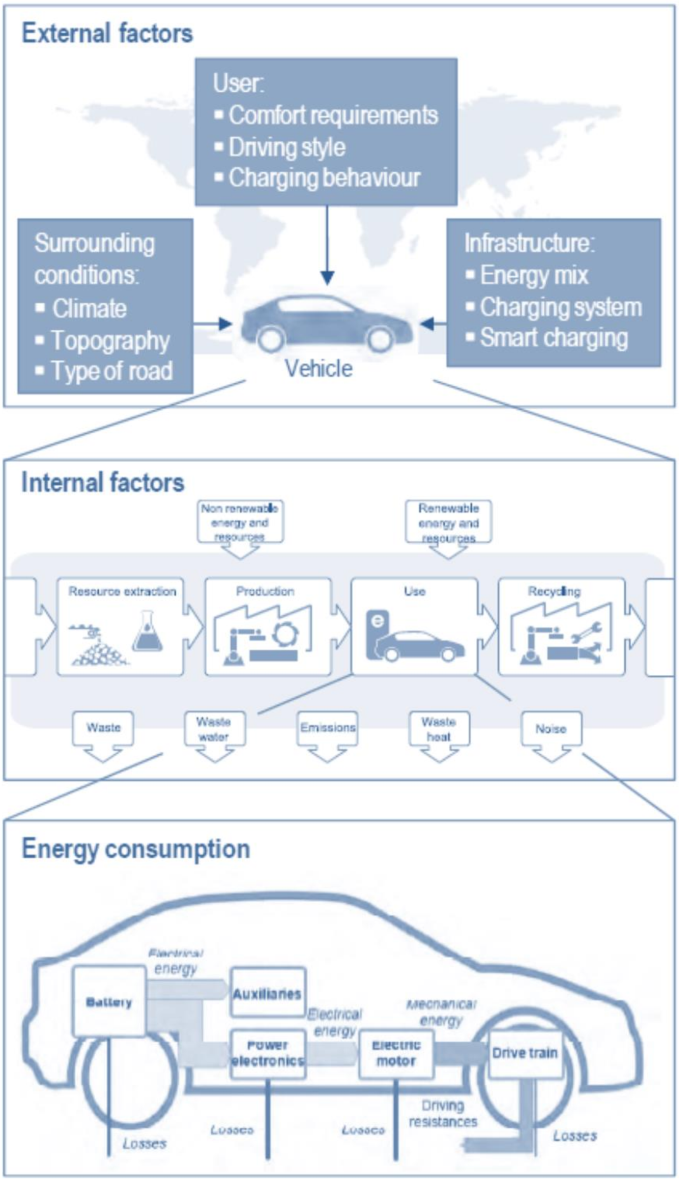

Figure 3.26 LCA framework for electric vehicles

- <u>Vehicle</u>

In the use phase-specific characteristics of the vehicle influence the energy. These factors are considered internal in this framework as they are inherent properties of the vehicle.

- <u>User</u>

The use of the EV influences the environmental impact of the EV through the driving and charging behaviour as well as through the intensity of the use of auxiliaries. A more aggressive driving style leads to a higher energy consumption whereas a more cautious driving style results in an efficiently use of energy. Depending on the charging behaviour and the willingness to install renewable energy specifically for the EV (e.g. in the form of solar panels), the share of renewable energy can be increased significantly compared to the use of grid energy in many countries.

➢ Infrastructure

The electricity mix is one of the most crucial parameters for the LCA calculation. Using a mix based entirely on renewable energies delivers a completely different result than an energy mix based on fossil fuels. Choosing the adequate mix which reflects the real-world situation and leads to fair and reliable results is challenging.

In many LCA's, an energy mix is used which is based entirely on renewable energy. However, often it is not clear if this represents the actual grid situation or if it is a case of crediting renewable energy to the EV rather than a different use. In the latter case, it must be considered if the crediting can be justified. The charging of EVs can in principle often be carried out at regular household plugs. Yet, often more sophisticated solutions are required at workplaces or in public areas to allow adequate and safe charging. Depending on the conditions of the site the installation of these charging stations demands major building activities. These activities can be significant for specific scenarios in which only one or a few vehicles use one charging station. The available charging infrastructure also influences the options of smart charging. Smart charging applications can increase the share of renewable energy used to charge the EV.

➢ Surrounding Conditions

The surrounding conditions influence the environmental impact of EVs. The climate, the topography and the type of road are identified as significant factors for energy consumption. The climate influences the need for heating and cooling appliances in the vehicle. The temperature varies both on a seasonal as well as on a daily level leading to a fluctuation of the energy consumption. Depending on the interaction of temperature and humidity the windshield of the car can fog up and require ventilation or the use of the air conditioning and/or heating. Currently, resistance heating is mostly applied in EVs.

Recycling of Batteries Possibly Used in Ground-Vehicles (e.g. Towing-Tractor) or Aircraft

The interest in sustainable vehicles, namely hybrid and/or electric (HEV, BEV), is increasing worldwide due to the growing concern about global warming and air pollution in large urban cities**.** Predictions suggest that hybrid and/or electric vehicles in the year 2035 will have a 35% share of the automobile market, with an associated, considerable reduction of CO2 emissions. To be successfully achieved, this important goal requires an efficient power source for the electric engine and, given its high energy density, long life, and rate capability, the lithium-ion battery is an ideal candidate for this purpose.

For consumer electronics, e.g., for powering mobile phones, only a single cell is sufficient, whereas car driving battery packs require the assemblage of many cells and the inclusion of a safety battery management system (BMS).

The worldwide reserves of lithium carbonate (i.e., the lithium main natural source) are still large. Considering that the yearly production amounts to about 0.16 M tons and that ~0.5 kg of Li_2CO_3 are needed per kWh battery, we can estimate from 80 to 100 years of reserves. Nevertheless, almost 70% of the global lithium deposits are concentrated in South America's ABC (Argentina, Bolivia, and Chile) and this poses an inherent risk for the accessibility of the raw material since unexpected events may condition the supply with a resulting impact on the battery price and consequently on the vehicle cost.

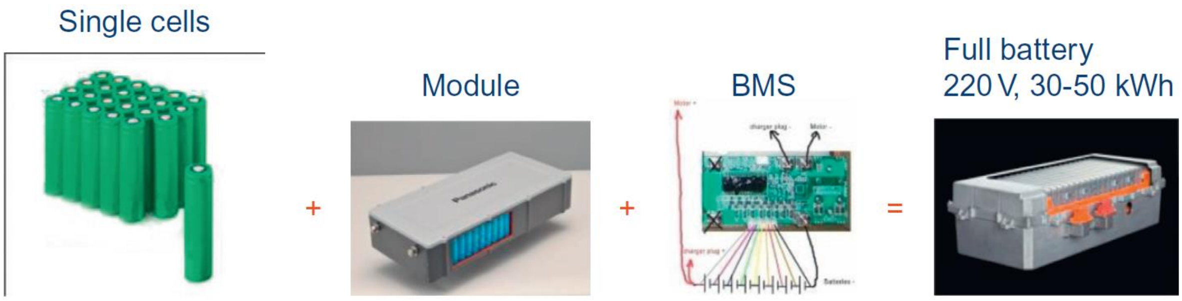

Figure 3.27 - Battery pack as BEV power system.

Furthermore, one has to consider that lithium is also the material of choice for applications other than batteries, including pharmaceuticals, ceramics, and glasses. Actually, the present consumption rate of lithium by OEMs is limited to a minor fraction, accounting for only about one-quarter of the current lithium production. However, in the prospect of large road diffusion of BEVs (1 million expected in 2020), the amount of lithium needed to meet the market demand is expected to increase considerably. The prices of lithium constantly increased over the last 10 years; at time of publication, prices were $5500–6000 per ton of lithium carbonate, depending on applications. Accordingly, considerable increases are expected if the demand rises. To limit the risks, many battery materials manufactures underwent investment in partnerships with the South American ABC countries to secure the lithium supply and hence, to control prices fluctuations.

The above considerations clearly outline the need for recycling lithium car batteries once they have exhausted their operational life, with the final goal of reusing them back to the car manufacturers. The idea is well represented by the general scheme reported below, as proposed by the Japanese Sumitomo company, see Figure 3.28. The future of battery recycling, however, is still uncertain.

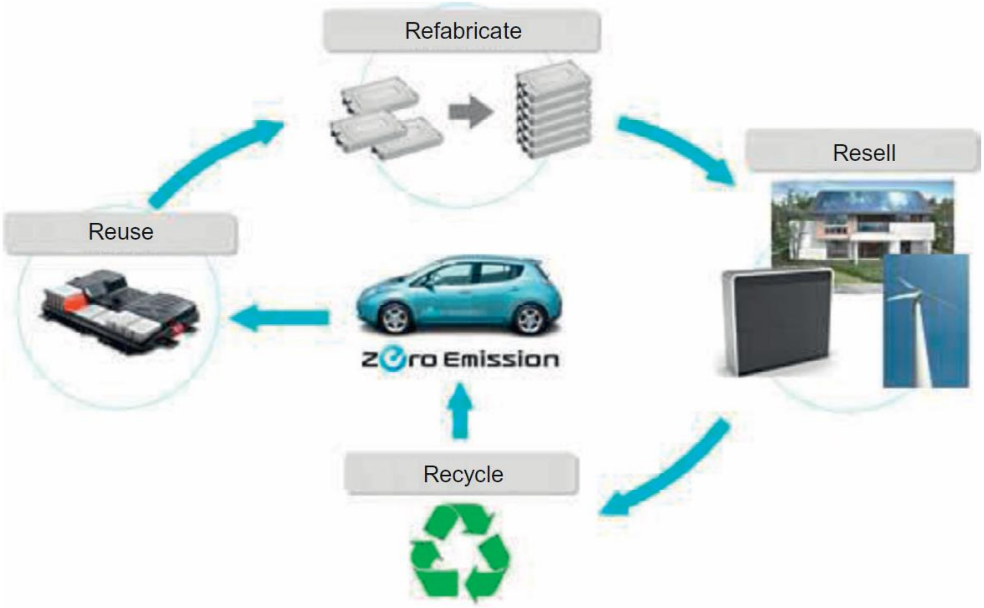

Figure 3.28 - General operational loop for EV battery saving

The main goal of recycling is that of separating battery components, as well as of removing waste from the environment. However, the process is affected by a series of issues that make it very challenging. About 100,000 tons of spent batteries are forecast in the prospect of 1 million EV cars on the road and their treatment is not straightforward.

The main problem is in the collection rate, which is still at a very limited extent, even for lithium batteries used in mobile electronic devices. Although the circulating number of these devices, and hence of their batteries, is extremely high, the collection is scarce for a series of reasons. First, there are not many lithium battery collection points in the municipalities. In principle, the shops selling lithium battery-operating devices should serve as collection points for the related exhausted batteries. However, this rarely happens and the customer, out of laziness or forgetfulness, tends to drop the old telephone with the included battery in a drawer. The problem is serious to the point that often the capacity of the plants is not matched by the number of received spent batteries. Obviously, the situation is even more of concern for the car batteries, considering the very limited number of EVs presently in the road.

Another serious issue is associated with the intrinsic safety risk owing to the high reactivity of the lithium batteries, especially if they arrive at the recycling plant still with a residual charge or if they are damaged. In fact, if overheated or overcharged, as it may happen by shorting when they are stored in masses, the batteries can enter a state of thermal runaway which can eventually lead to fire or even explosion. Besides, metallic lithium can also form on the graphite anode by overcharge and/or by abnormal deposition, whose high reactivity greatly increases the risk of explosion. The energy released by these explosions is powerful enough to melt the metal containers with resulting serious safety hazards.

The other serious issue is related to the fact that the lithium battery market is in continuous evolution with the advent of many new chemistries. Further, in addition to the rechargeable Li-ion batteries, also primary lithium batteries, using cathodes such as manganese oxide or thionyl and sulfuryl chloride, are still in the market and they may arrive at the plants as well. Finally, also the electrolyte may widely change, passing from a variety of liquid organic solutions to polymer membranes. Clearly, this high diversity makes it difficult to develop a universally valid recycling process, as well as affecting its economics, since the new chemistries may not involve components worth being recovered.

Indeed, the European Commission has mandated a Battery and Accumulator Directive, which imposes to the state members the following targets.

● *A 45% collection rate for waste-portable batteries to be met by September 2016.*

● *A recycling efficiency to ensure that a high proportion of the weight of waste batteries is recycled, this including 65% of lead-acid, 75% of nickel-cadmium, and 50% of "other waste batteries," the latter likely referring to lithium batteries.*

Considering the present low economic value, these targets can be met only if subsidies are provided, usually adding a tax to each manufactured battery, as indeed is the case. Under this scheme, battery recycling plants are now operating in Europe (e.g., Batrec in Switzerland, Umicore in Belgium, and SNAM and Recupyl in France) to honour the mandate.

Plants are also in force under different schemes in the United States (e.g., Toxco) and in Japan (e.g., Sony and Sumitomo Metal). Due to the still scarce production of lithium-ion batteries of EV types, the recycling is for the moment limited to the portable ones. However, EV battery recycling is expected to gain quite a significant importance in the years to come, this enhancing the role of the experience obtained with the present small-scale prototypes.

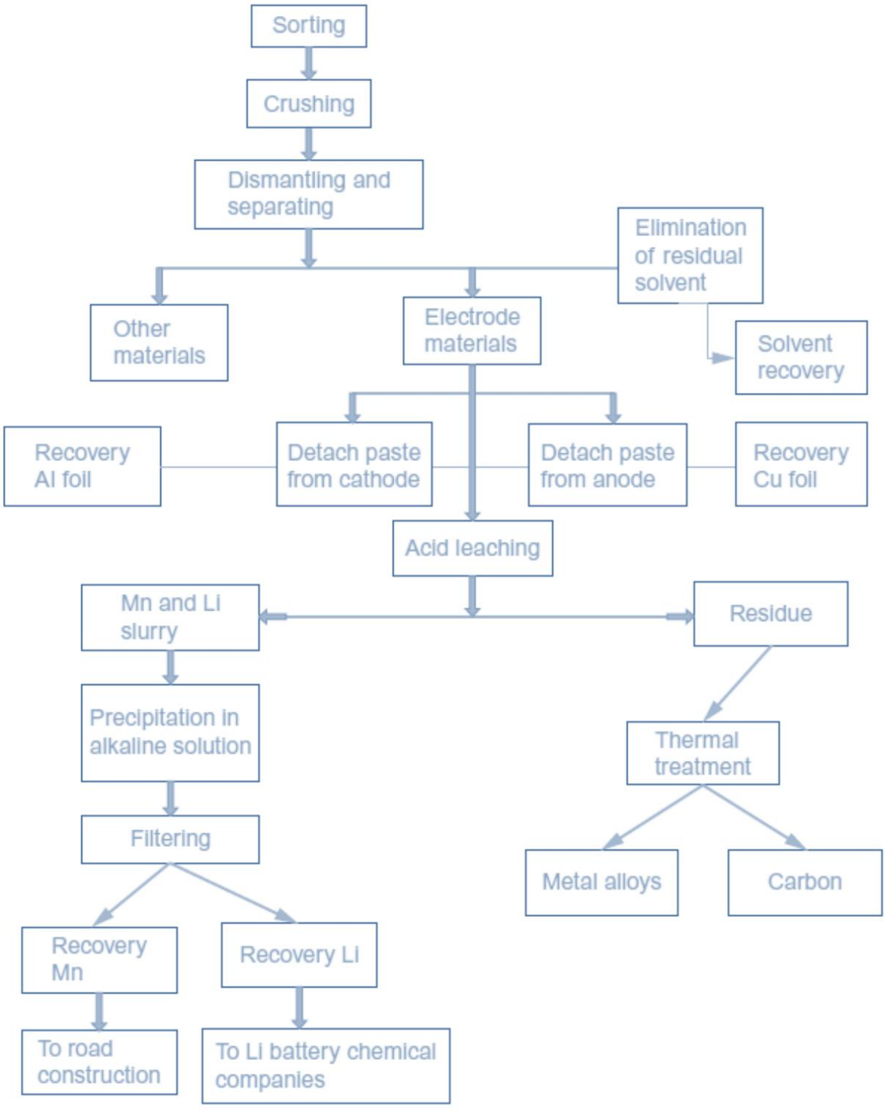

Figure 3.29 - Typical lithium battery recycling flow sheet

➢ <u>Government Regulations</u>

Battery recycling (Figure 3.29) has been a task for many years motivated by environmental awareness and waste legislation mandates. With the public's increase in environmental sensibility, growing attention is paid to the sustainable management of natural resources. The public also has an increasing concern with the hazardous properties of metals and substances, a concern that certainly encompasses batteries of all types. European (if not worldwide) regulations have designated all batteries as hazardous waste that require treatment before disposal, with the following tasks to be accomplished, in order of priority:

1. Waste reduction at the origin, employing cleaner products and processes.

2. Recovery of valuables from wastes, where possible.

3. Treatment of non-recoverable wastes to make them safe and disposable.

These regulations require large efforts to be devoted to the collection and recycling of batteries of any kind, despite the possibility that they may contain a low content in heavy metals. To cope with these directives, several recycling plants are in operation in Europe, the United States, and Japan. Initially, the activity was mainly restricted to zinc-carbon batteries, namely the common "dry" primary AA or AAA cylindrical cells that are largely present in the low-value electronic market. For these dry cells, regulations have been imposed requiring that they are produced as "mercury-free" systems, which is the case for European and American manufacturers. However, the market globalization has favoured circulation from countries where environmental sensitivity is not as acute as in Europe and the United States, with the result that a considerably large amount of mercury is still recovered when recycling these batteries. Interestingly, the majority of the plants are still treating mostly consumer batteries, such as the quoted dry cells, and the rechargeable NiCd and NiMH batteries, while little attention has thus far been devoted to the collection and the recycling of lithium batteries. On the contrary, recycling of conventional automotive batteries, such as starting lighting and ignition (SLI) lead-acid, are in full operation worldwide.

The low recycling rate of lithium batteries is rather surprising since they are products that strongly influence our everyday life. Due to their favourable characteristics, lithium-ion batteries are the power sources of choice in the consumer electronics market and, as such, are sold by several billion per year. Primary lithium batteries are mainly marketed to generic consumer markets for use in cameras, watches, and similar, whereas lithium-ion secondary batteries are marketed for mobile devices of increasing sophistication, such as cellular phones and laptop computers.

The large expansion of these markets (it is assumed that today billions of cellular phones are circulating worldwide) is evidence of the importance of the problem, which will only worsen with the expected advent of a high number of lithium-ion battery-powered electric cars. We need to increase the number of recycling plants for treating these batteries which, despite being rechargeable, will inevitably come to the end of their life at some point. Even though in the last few years protocols and plants have been developed in Europe, the United States, and Japan, much still needs to be done to assure a full collection and an effective recycling program for lithium-ion batteries. We hope that this review will provide the motivation and the stimulus for achieving this important goal, in the near future.