Advanced Aerodynamic Technologies for Future Green Regional Aircraft

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Abstract: *Future Green Regional Aircraft (GRA) will operate over airports located in the neighborhood of densely populated areas, with high frequency of takeoff/ landing events and, hence, strongly contribute to community noise and gaseous emissions. These issues currently limit further growth of traffic operated by regional airliners which, in the next future, will have to face even more stringent environmental normative worldwide and therefore re-designed to incorporate advanced active aerodynamic technologies.*

The new concept behind GRA is based on several mainstream technologies: airframe low-noise (LN), aerodynamic load control (LC) and load alleviation (LA). These technologies integrate relevant concepts for hybrid and natural laminar flow (HLC/NLF) wing, active control of wing movables and aeroelastic tailoring for LC/LA functions, passive means (micro-riblets) for turbulent flow drag reduction, innovative gapless architectures (droop nose, morphing flap) beside conventional high-lift devices (HLDs), active flow control through synthetic jets, low-noise solutions applied to HLDs (liners, fences), and to fuselage-mounted main and nose landing gears (bay/doors acoustic treatments, fairings, wheels hub cap).

The paper deals with the technological readiness level (TRL) assessment of the most promising technologies and overall integration in the new generation of GRA, as a highly optimized configuration able to meet requirements for FlighPath 2050.

Key Words: *natural laminar flow, active flow control, synthetic jets, highly optimized configuration*

1. INTRODUCTION

Different scenarios can be envisaged for the future European Transport System depending on many factors (social needs, economy, fossil oil price and availability, environmental concerns including noise and climate change, political choices and stability).

A possible visionary European Transport System should be based on a customer oriented [1], and an environmentally sustainable, cost efficient, safe, seamless and intermodal passenger friendly system aiming to ensure mobility and cohesion for the European citizens while enabling economic growth. More people and greater economic affluence mean more mobility and more transport.

Some studies suggest that the number of cars in the world will increase from around 700 million today to more than 3 billion in 2050, creating serious sustainability problems unless there is a transition towards lower and zero-emission vehicles and a different concept of mobility is introduced in an environmentally friendly way [2].

One future element of such an advanced transport system will be transportation using regional aircraft and small/regional airports assisted by an ICT infrastructure (Intelligent

Personalized Air Transport System) [2,3]. This new transport mode will enable fast travel in areas of Europe where high speed trains or traditional airline connections are unavailable and substitute road travel thus alleviating road congestion problems in a customer - and environmentally friendly way. It will contribute to the goal of enabling 4 hour door to door travel all over Europe [3].

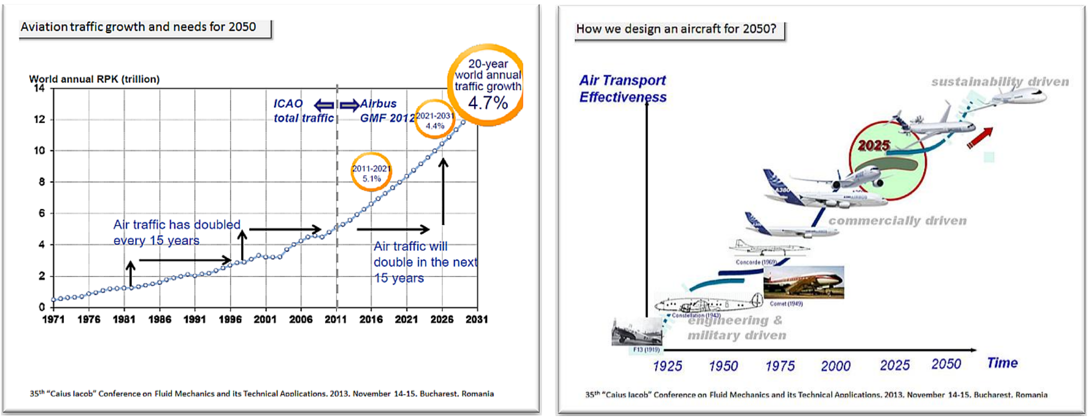


Fig. 1 – Aircraft design towards 2050

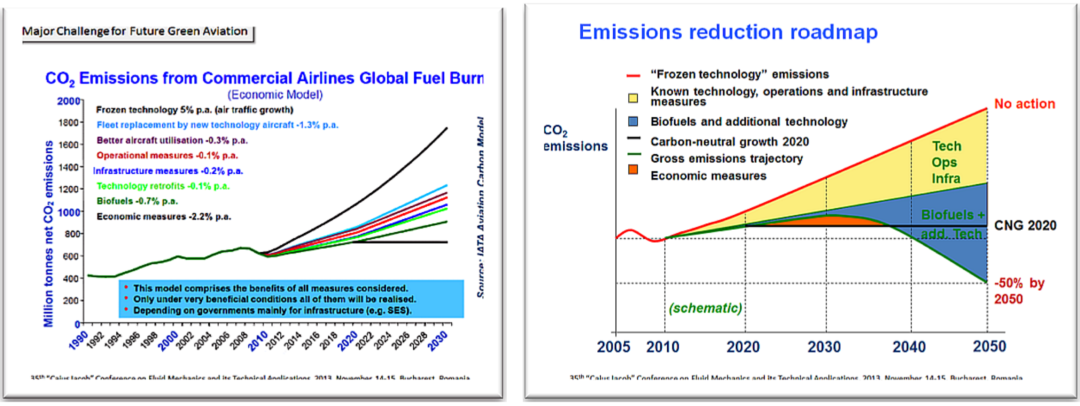


Fig. 2 – Emission reduction policy for 2050

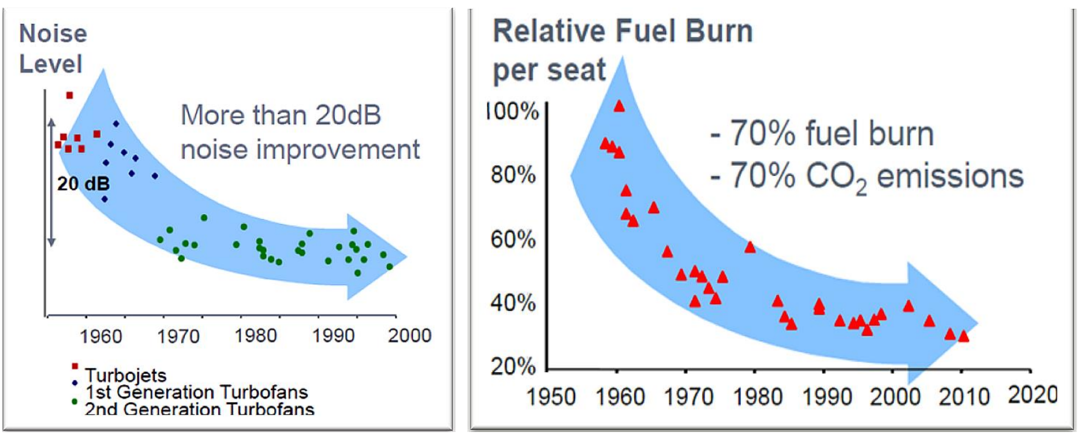
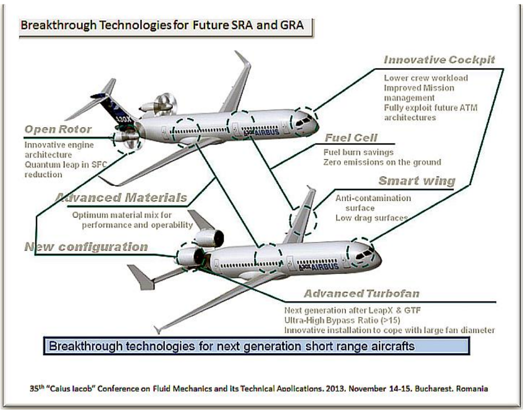


Fig. 3 – Fuel burn and noise reduction trends

2. KEY DESIGN OBJECTIVES:

- 50% cut in CO2 emissions per passenger/Km
- 80% cut in NOx emissions
- 50% cut in perceived aircraft noise
- Five-fold reduction in accidents
- ATS capable of 16 mio. Flights a year;
- 99% of all flights within 15 min. of timetable

3. TECHNOLOGIES FOR GRA – SELECTION POOL



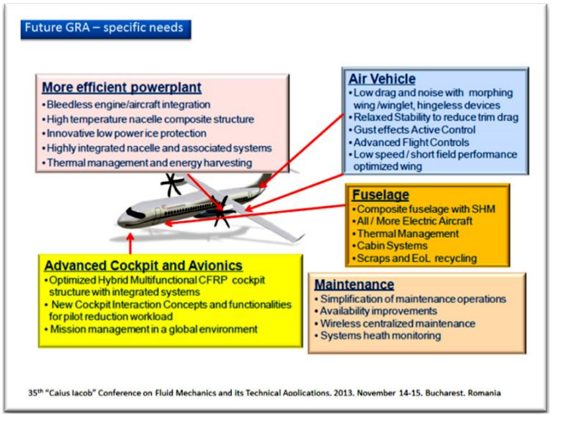


Fig. 4 – Technologies for future GRA – selection pool

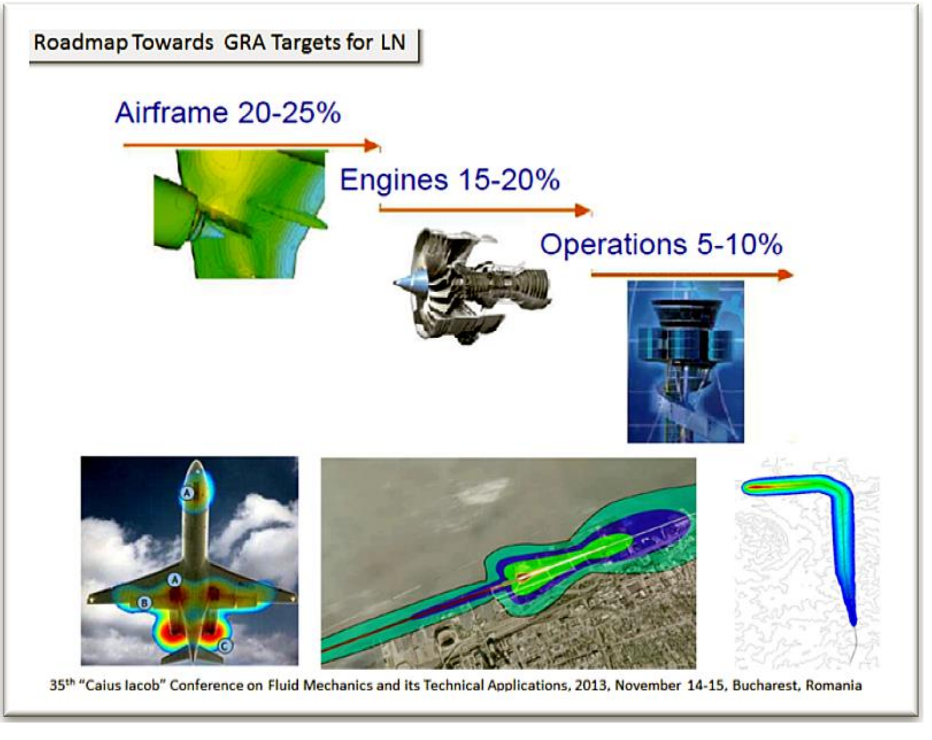
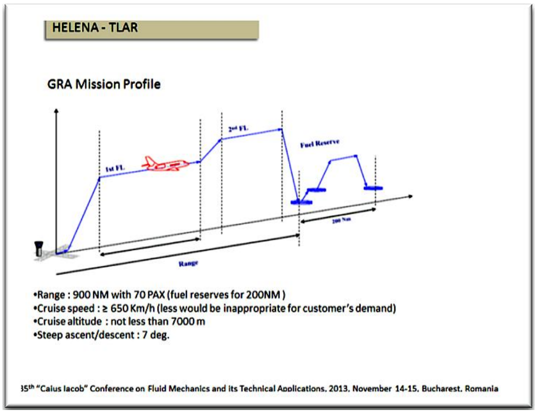


Fig. 5 – Roadmap for GRA targets – LowNoise technologies

4. TOP LEVEL AIRCRAFT REQUIREMENTS (TLAR) FOR GRA



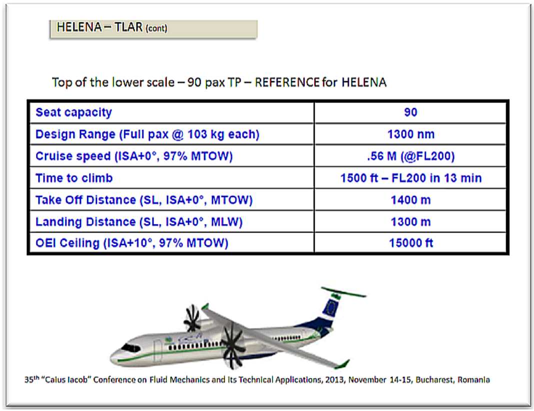


Fig. 6 – TLAR for GRA – HELENA concept

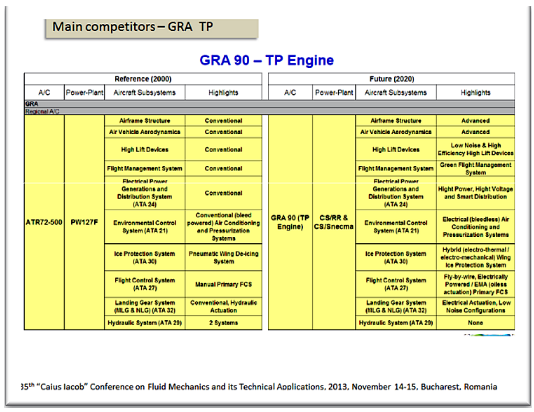
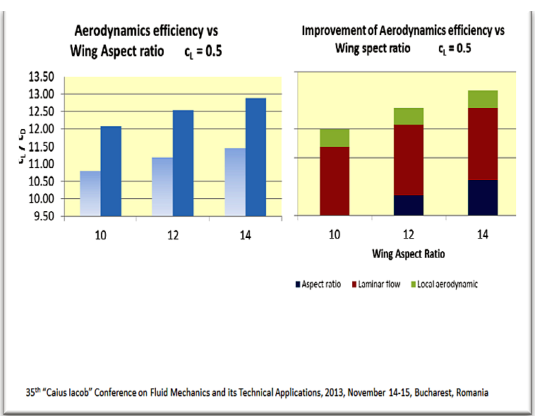


Fig. 7 – Cross-correlations for GRA concept



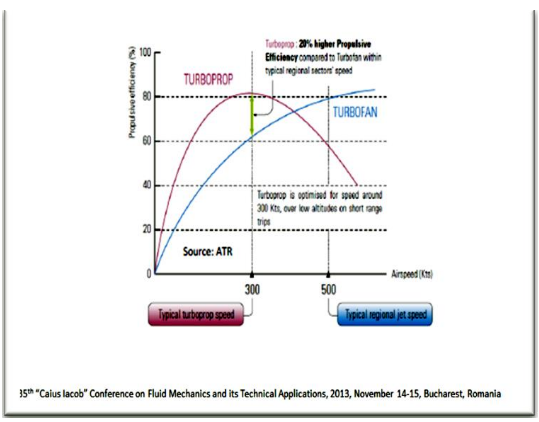
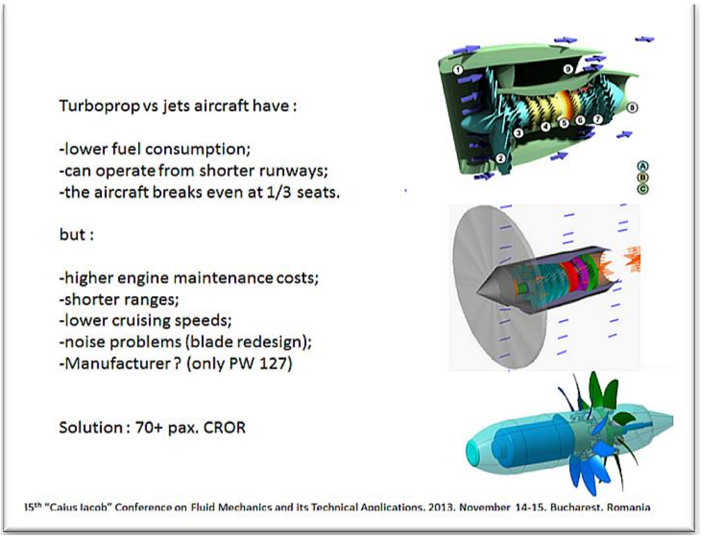


Fig. 8 – Efficiency study for TP concept for GRA



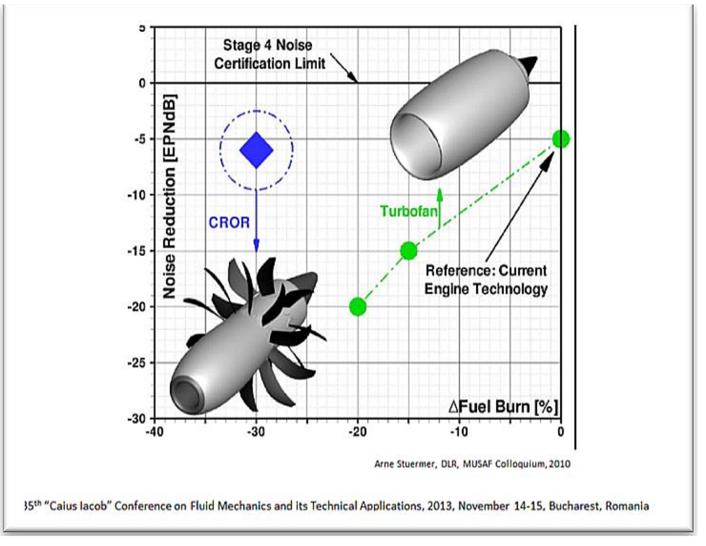


Fig. 9 – Case for OR in GRA concept

In order to allow wide social acceptance of small aircraft as transportation means, so acquiring relevant market position, the careful consideration of safety and comfort issues is very relevant. Safety has to be considered more and more a relevant issue in the project, due to the need of allowing regular people, not provided with high piloting skills, to pilot the aircraft while assuring safety levels not lower than the required ones (currently the less restrictive for EASA CS23 aircraft is 10exp-6 catastrophic event per flight hour probability) or even higher. To achieve this result, very relevant effort has to be devoted to provide the vehicle with extensive flight automation capabilities in order to support the pilot in command or even to completely substitute him/her in some nominal conditions (involving high pilot workload or simply repetitive tasks) and in emergency situations requiring high skill to be managed. The achievement of this required level of safety through automation calls for the implementation on board of small aircraft of some of the most recent and innovative technologies used in the large commercial aircraft framework. Nevertheless, a "simple" technology transfer from large to small aviation is not possible, due not only to technical reasons but also – and this is the most relevant aspect – to budget reasons: large aircraft technologies become not affordable for the application on small vehicles. This motivates the need of performing extensive research and development activities in order to design suitable low cost technologies aiming to provide small CS23 aircraft with suitable automation and safety-improving functionalities.

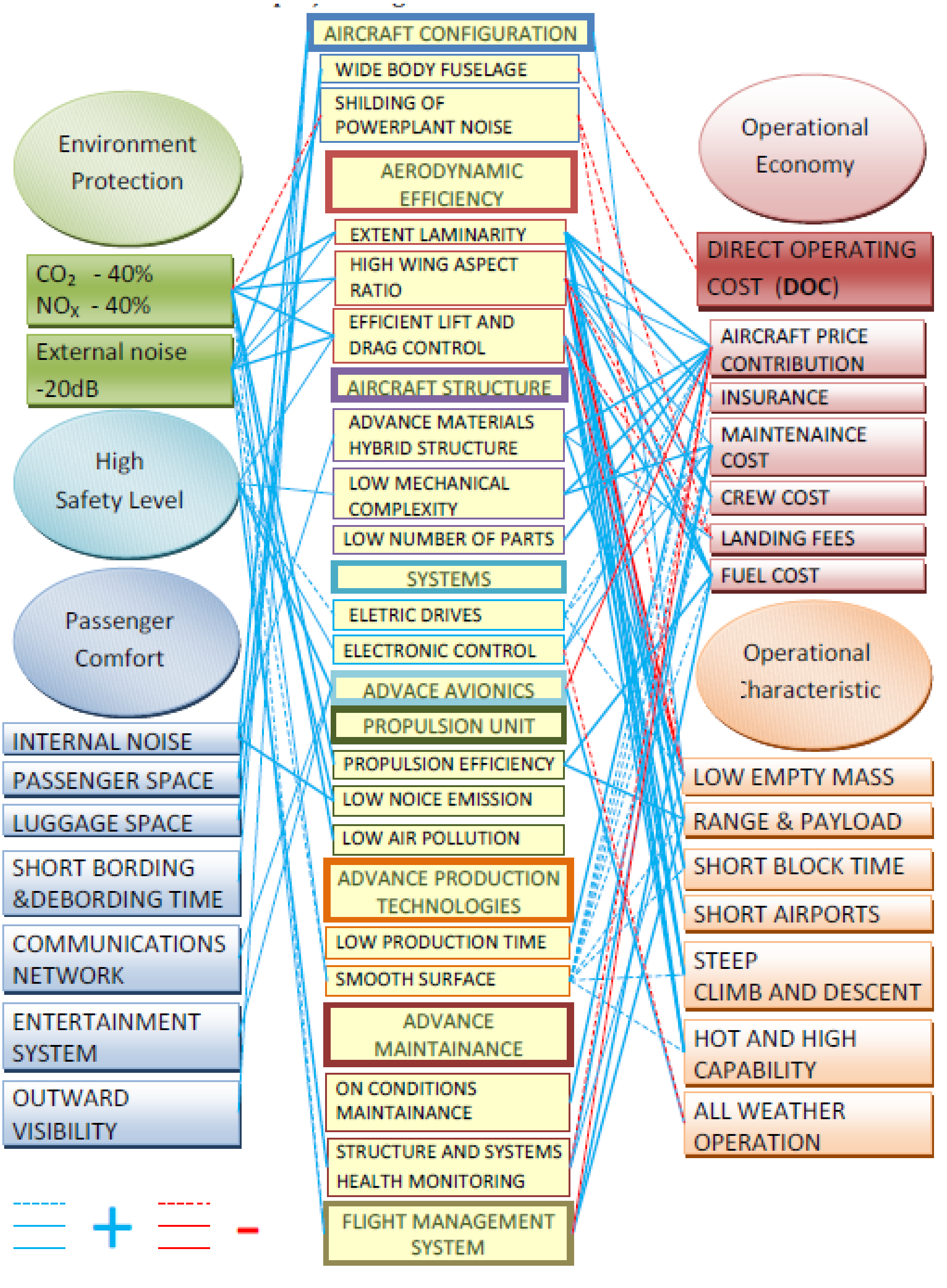


Fig. 10 – HELENA technology decision tree

R&D activities include the design of a suitable cost effective highly safe fly-by-wire architecture for small aircraft, which has to incorporate wide range of systems able to:

- support the pilot at decision making level during all the flight phases;
- support the pilot in performing the guidance or substitute him/her in recurring functions;
- maximize the automation level in order to improve flight safety and reduce required piloting skills;
- prevent piloting errors through monitoring of the reference command and automatic system override when needed;
- improve the situational awareness of the pilot (and of the automatic system);
- reduce the pilot workload;
- extend the usability of the vehicle, in order to include all weather all time operations in safe conditions.

Also relevant issue to be considered in the project is the comfort of the flight, in order to ease the social acceptance of this transportation means.

Also this issue becomes a technological challenge, due to the need to use automatic systems for gust alleviation, for instance. Also in this case, the specific application on small vehicles, so the need of reducing final product market price, prevents the application of technologies used on large aircraft and implies the need of specifically devoted research and development activities [3].

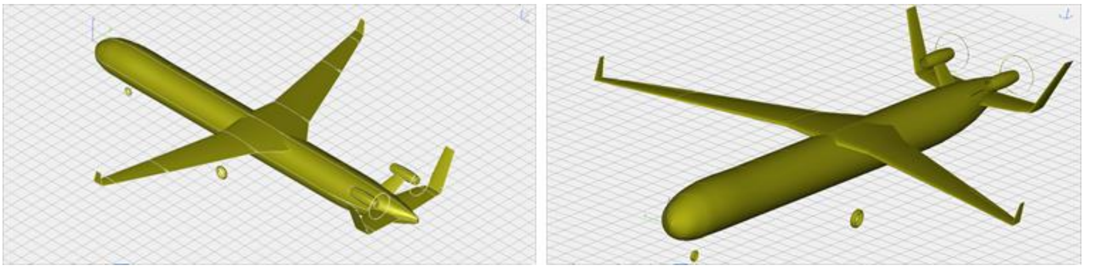


Fig. 11 – HELENA GRA concept

Fig. 12 – HELENA GRA demonstrator at INCAS

5. THEMATIC AREAS FOR A HELENA GRA CONCEPT

5.1 GRA Airframe

A.1 - More competitive production plant for regional aircraft
A.2 - Application of new materials and optimization of progressive manufacture technologies for production of regional aircraft

A.1 - More competitive production plant

Structural parts reduction

- Reduction of number of components of composite structures (Not „Black Metal“), reduction of number of mechanical fasteners
- Reduction of number of components of metal structures
- Highly integrated structures

More Automation for metal and composites

- More automation for metal structures, cost effective all-metal structure assembly
- Automation and robots in low-volume production for metal and composites
- Reduction of operations / labour consumption
- Innovations for production rigs/fixtures
- Automation for composite production, out of autoclave methods, advanced moulds
- Repeatability/quality for non-prepreg composite technologies

Optimized processes

- Production management, processes simulation - Virtual Enterprise/Optimized processes

Hybrid structures assembly

- Advanced Design /Manufacture Technologies for Hybrid Structures, hybrid joints, Interactions of hybrid parts with respect to corrosion and production technologies

Joining of composite parts using standardized metallic connection components, strength verifications and hybrid joints testing

Thermoplastic Composites

- Integrated thermoplastic structural parts
- Thermoplastic joining, welding
- Design of the new shapes of thermoplastic parts with using of forming process simulation

Evaluation of mechanical and physical properties, damage mechanism – too low TRL?

Joining of composite parts using standardized metallic connection components, strength verifications and hybrid joints testing

A.2 - Application of new materials and optimization of progressive manufacture technologies for production of regional aircraft

Innovations in Materials and Processes

- Use of new and alternative metal materials for structural parts
- Use of new alloys in aircraft engines, APU and aircraft instruments
- New alloys for casting with directed crystallization and monocrystals

- Heat treatment processes for new/alternative materials
- Material analysis of innovative materials – testing of properties – creep, low cycle and high cycle fatigue, evaluation of damage mechanism – TRL?
- Optimized composite materials with high strength properties

Manufacture Technologies – Casting

- Casting technologies for new superalloys
- Characterisation of technological variants with respect to fatigue and creep properties
- New techniques for casting by directed crystallization with insulations
- Use of ceramic cores for specific engine components

Manufacturing Technologies – Machining

- Efficient machining technologies for critical engine parts (compressor, highly accurate gear wheels)
- Advanced machining technologies for structural parts
- Unconventional machining methods for metal parts – laser
- Optimized machining of heat resistant Ni/Co alloys
- New forming technologies of heat-resistant parts
- Robotic/automated composite machining

Innovations in Coating - turbomachinery

- Efficient use of Chemical Vapor Deposition (CVD) coating
- Paint/coating system using active nanoparticles for icing protection of aircraft
- Paint/coating system for improvement of aerodynamic performance (e.g. insect/dust/ contamination /ice accretion etc.)
- Efficient ecological anti-corrosion protection (replacement of cadmium plating, chromating)

5.2 GRA Systems

S.1 - Efficient operation of small aircraft with affordable health monitoring systems
S.2 - More electric small aircraft
S.3 - Comfortable and safe cabin for small aircraft
S.4 - Affordable avionic solutions for small aircraft

S.1 - Efficient operation of small aircraft with affordable health monitoring systems

Highly Efficient Operation – Health Monitoring for Aircraft Systems

- Aircraft systems health monitoring
- Engine health monitoring
- EHA and EMA health monitoring based on the operational modes
- Landing gear with health monitoring
- Optical sensors and systems for HM?
- Smart HM integrated with power distribution system and/ or utilizing wireless networks/ sensors and energy harvesting

Highly Efficient Operation – Structural Health Monitoring (SHM)

- Affordable solution for structural health monitoring systems – metal structures
- Affordable solution for structural health monitoring systems for composite structures
- Corrosion monitoring

- Optimized maintenance system (MRO)
- Optical sensors and systems for SHM
- SW simulations for structural health monitoring and NDE of composite/metal structures
- SW simulations for optimized maintenance system including optimized NDE (Non-Destructive Examination)
- Monitoring of structural frequency characteristics for operational damage detection

Smart and flexible SHM sensors including energy harvesting and wireless

S.2 - More electric regional aircraft

- Advanced electric power generation, conversion, distribution and management to reduce size, weight and costs
- High voltage power generation and distribution, Electric power generation
- Electric system reliability
    - Redundancy, separation and diversification of EPS (Electric Power Supply)
    - Reliability Analyses of dependent failures (Common Modes)
    - New methods of safety critical, high reliable control system development (hw and sw design)
- Advanced electric power distribution and management
- Electric power distribution
- Electromechanical actuation (EMA)
- Hybrid power systems including airworthy batteries and decentralised energy storage(e.g. supercapacitors) fault tolerant battery mgmt&control
- Electric brake system
- Bleedless engine
- Efficient anti /de-icing, electrical de-icing, autonomous de-icing
- Fuel metering systems
- Engine control systems (EEC/FADEC)

S.3 - Comfortable and safe cabin for small aircraft

Integration of New Technologies for Environmental Control Systems

- Smart ECS
- Fully electric distributed ECS

More Safety & Comfort for General Aviation

- Active noise control
- Active noise cancellation (interior or exterior)
- Multifunctional insulation
- Cabin comfort prediction
- Cabin crashworthiness
- Lightweight seats
- Operational versatility – unpaved airfield, float systems for water landing, remote operation
- Human Reliability Enhancement
- Effective training and flight simulation
- Particular Risk Assessment
- Passengers wireless connectivity
- Advanced and flexible interior lighting

S.4 - Affordable avionic solutions for small aircraft

Affordable avionic solutions for small aircraft

- Affordable SESAR operation
- Multimodal cockpit
    - voice control, ATC communication visualisation
    - trajectory/energy optimization visualization
    - pilot advisory/monitoring system
    - Reduce workload by introducing more automation and new modalities into the flight deck (integration of info from various sources)
    - Direct voice control; Touch interaction control & reduce fingerprint; Data fusion (integration of info from various sources)
    - Advanced graphics (new functions need higher graphics processing) – multi- and many-core processors, heterogeneous processors, GPU, OpenGL to reduce burden on master processor, OpenCL
- Avionics
    - Cost effective navigation systems (incl. augmentation) for operation in the future ATM environment; on-ground navigation to support gate-to-gate navigation
    - Cost effective Cooperative/Non-cooperative Surveillance for all aircraft classes (interoperability with ATR)
    - Affordable CPDLC like Datalink for operations in future ATM
- Flexible and scalable avionics
    - Modular Distributed Avionics
    - Smart Redundancy Management Mechanisms
    - Wireless networks
    - Security mechanisms for distributed avionics
- Methods / tooling for acceleration of the system / SW development lifecycle
    - Integrated systems / safety engineering
    - Incremental cert
    - Auto-code
    - Portable SW for accelerated development and re-certification
- Reduce weight, enhance safety and ride comfort, reduce cost and assist airframe designers through advanced FBW functions
    - Smart Redundancy Management Mechanisms
    - High reliability actuator / control
    - Parameter based controls

S.5 - Cost effective fly-by-wire architecture, systems and algorithms for regional aircraft

Systems and algorithms to improve safety for small aircraft

- Innovative cockpit concept and interaction means to reduce pilot workload and improve situational awareness
- Automatic landing system for nominal and emergency conditions
- Advanced decision support system in normal and emergency conditions for MFDs
- Smart Autopilot with envelope and failure protection
- Fully automatic system for mid-air 3D/4D navigation
- Multi sensor based terrain awareness and avoidance system
- Multi sensor based separation and collision avoidance system

- Weather awareness and management system
- Artificial vision system for all weather all time application

Systems and algorithms to improve comfort for small aircraft

- Gust alleviation system

6. SOME CONCLUSIONS

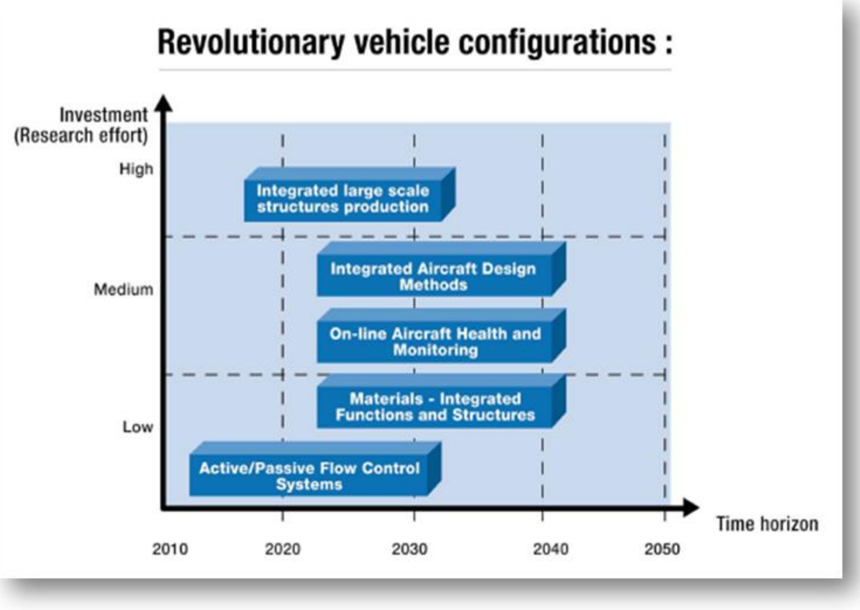


Fig. 13 – HELENA GRA technology roadmap

HELENA GRA is a proposed concept for a future generation of regional aircrafts, to be in service in 2020. This is part of a broader interest to have a new ATS tailored to the needs and requirements in Europe and also orientated towards a global market.

At the same time, from industrial perspective, a new generation GRA has the capability to further extend technological capabilities emerging from latest developments in a large selection pool, where both low TRL and very high TRL concepts coexist.

The development roadmap for a future GRA is a lively process, where ACARE goals for a new ATS are aimed for a steep change in the overall R&D process. Proposed HELENA concept is a solid demonstration at aircraft level for the new generation of green regional aircraft to emerge in the next 20 years.

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