EFFICIENT SYSTEMS AND PROPULSION FOR SMALL AIRCRAFT

Proposal full title: **Efficient Systems and Propulsion for Small Aircraft**

Proposal acronym: **ESPOSA**

FP7 Program: 4th call FP7 EU - ACTIVITY 7.1.4. IMPROVING COST EFFICIENCY

Type of funding scheme: Level 2 - large scale integrating 'Collaborative Projects' (CP-IP)

Work programme topic: AAT.2011.4.4-4. Integrated approach to efficient propulsion and related aircraft systems for small-size aircraft

Coordinating organization: První brněnská strojírna Velká Bíteš, a.s. (CZ)

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Budget planned: **42,4 mil. EUR** (EC contribution requested 28 mil. EUR)

List of participants:

No	Company legal name	Org. short name	Country	Type of organization
1 (CO)	PRVNI BRNENSKA STROJIRNA VELKA BITES A.S.	PBS	CZ	engine manufacturer
2	ZAPOROZHYE MACHINE-BUILDING DESIGN BUREAU PROGRESS STATE ENTERPRISE NAMED AFTER ACADEMICIAN A.G. IVCHENKO	SE Ivchenko-Progress	UA	engine manufacturer
3	AVIO S.P.A	AVIO	IT	engine component manufacturer
4	TECHSPACE AERO SA	TA	BE	engine component manufacturer
5	Motor Sich JSC	MOTOR SICH JSC	UA	engine manufacturer
6	WYTWORNIA SPRZETU KOMUNIKACYJNEGO PZL - RZESZOW SA	WSKRZ	PL	engine component manufacturer
7	HONEYWELL INTERNATIONAL SRO	HON	CZ	engine component/syst. manuf.
8	TUSAŞ Motor Sanayii A.Ş.	TEI	TR	engine component manufacturer
9	UNIS, a.s.	UNS	CZ	systems producer (SME)
10	ZOLLERN GmbH & Co. KG	ZOLLERN	DE	systems producer
11	ATARD savunma ve havacilik Inc.	ATARD	TR	systems producer (SME)
12	MATERIALS ENGINEERING RESEARCH LABORATORY LIMITED	MERL	UK	design engineering (SME)
13	SYSGO AG	SYSDE	DE	systems producer (SME)
14	Jihostroj a.s.	JIHOSTROJ	CZ	systems producer
15	PIAGGIO AERO INDUSTRIES SPA	PAI	IT	aircraft producer
16	Marganski&Myslowski Zaklady Lotnicze Sp. z o.o.	M&M	PL	aircraft producer (SME)
17	Grob Aircraft AG	GROB	DE	aircraft producer (SME)
18	EVEKTOR, spol. s.r.o.	EVE	CZ	aircraft producer
19	Winner scs	WINNERHELICO	BE	aircraft producer (SME)
20	FUNDACION TECNALIA RESEARCH & INNOVATION	TECNALIA	ES	research establishment
21	CENTRO ITALIANO RICERCHE AEROSPAZIALI SCPA	CIRA	IT	research establishment
22	INSTYTUT LOTNICTWA	ILOT	PL	research establishment
23	VYZKUMNY A ZKUSEBNI LETECKY USTAV A.S.	VZLU	CZ	research establishment
24	CENTRE DE RECHERCHE EN AERONAUTIQUE ASBL - CENAERO	CENAERO	BE	research establishment (SME)
25	INSTITUTUL NATIONAL DE CERCETARI AEROSPATIALE ELIE CARAFOLI - I.N.C.A.S. SA	INCAS	RO	research establishment (SME)
26	STICHTING NATIONAAL LUCHT- EN RUIMTEVAARTLABORATORIUM	NLR	NL	research establishment
27	CENTRAL INSTITUTE OF AVIATION MOTORS	CIAM	RU	research establishment
28	INSTITUTUL NATIONAL DE CERCETARE-DEZVOLTARE TURBOMOTOARE - COMOTI	COMOTI	RO	research establishment (SME)
29	VALTION TEKNILLINEN TUTKIMUSKESKUS	VTT	FI	research establishment
30	FRAUNHOFER-GESELLSCHAFT ZUR FÖRDERUNG DER ANGEWANDTEN FORSCHUNG E.V.	IPT	DE	research establishment
31	TECHNISCHE UNIVERSITEIT DELFT	TUD	NL	university
32	TECHNISCHE UNIVERSITAET MUENCHEN	TUM	DE	university
33	POLITECHNIKA WARSZAWSKA	PW	PL	university
34	BUDAPESTI MUSZAKI ES GAZDASAGTUDOMANYI EGYETEM	BME	HU	university
35	VYSOKE UCENI TECHNICKE V BRNE	VUT	CZ	university
36	TECHNICAL UNIVERSITY KOSICE	TUK	SK	university
37	POLITECHNIKA RZESZOWSKA IM IGNACEGO LUKASIEWICZA PRZ	PRZ	PL	university
38	TOBB EKONOMI VE TEKNOLOJI UNIVERSITESI	TOBB ETU	TR	university
39	UNIVERSITA DI PADOVA	UNIPA	IT	university

Proposal Abstract

The ESPOSA project will develop and integrate novel design and manufacture technologies for a range of small gas turbine engines up to approx. 1000 kW to provide aircraft manufacturers with **better choice of modern propulsion units.** It will also deal with engine related systems which contribute to the overall propulsion unit efficiency, safety and **pilot workload reduction.** Through the newly developed design tools and methodologies for the engine/airframe integration the project will also contribute to the improved readiness for new turbine engines installation into aircraft.

New technologies and knowledge gained through the ESPOSA project will provide European general aviation industry with substantially improved ability to develop and use affordable and environmentally acceptable propulsion units and reliable aircraft systems minimizing operating costs, while increasing the level of safety. **The new engine systems and engine technologies gained from ESPOSA should deliver 10-14% reduction in direct operating costs (DOC) and reduce significantly the pilot workload.** The ESPOSA project is oriented on turbine engine technologies tailored for a small aircraft up to 19 seats (under CS-23/FAR23 regulations) operated on the scheduled and non-scheduled flights.

Research work comprises performance improvements of key engine components, their improved manufacture in terms of costs and quality. New engine component technologies will be backed by novel modern electronic engine control based on COTS, pioneering the engine health monitoring for small engines and providing advanced more electric solutions for fuel and propeller control systems. The project also addresses problematic design areas connected with turboprop/turboshaft engine installation into airframe structure, including the use of composite materials. The work will be conducted taking into account specifics of different aircraft configurations.

Project activities will include extensive validation on the test rigs. The most appropriate technologies according to value/cost benefit will be selected and integrated into functional complexes and further evaluated on the engine test beds. The functionality of certain project outcomes will also be demonstrated and validated in flight conditions to reach higher proves level.

The ESPOSA project will also employ those technologies already developed for larger aircraft or those outside of aeronautics to provide affordable technology solutions for small aircraft. The project encourages both aircraft and engine producers in using new technologies for gas turbine engines, in demonstrating their feasibility and in proving their advantages for operators.

The content of RTD work of ESPOSA is complementary to the activities and technology domains addressed by the JTI Clean Sky. The ESPOSA project will fully employ results gained in propulsion area from the integrated project CESAR (Cost-Effective Small AiRcraft - AIP5-CT-2006-030888) and several other FP projects.

Project rationale

Propulsion as a key element

The further development of general aviation (GA) and any forthcoming steps in this area are substantially limited by availability of modern certified propulsion units and reliable aircraft systems. Any kind of aircraft/rotorcraft configuration for future air taxi or regional transport will desire efficient and environmentally acceptable propulsion unit.

As the development of new engine requires much more time than design of particular aircraft in this category, the aircraft are usually designed and built on existing engines. It is obvious that an adjustment and customization of engines to desired performance for particular aircraft is often necessary, but starting a new engine development from scratch is often impossible. According to the aircraft manufacturers a step-change in efficiency of air transport services provided by their small commercial aircraft cannot be made without new efficient systems and propulsion units.

Limited choice

There is a very limited choice of turboprop and turboshaft engines on the current market in the power range below 1000 kW. One sort of quite affordable engines is unfortunately technically very obsolete. The obsolescence is not connected only with engine itself but also with propulsion systems like engine control, diagnostics and health monitoring systems having an impact on pilot workload and higher operating costs. The second sort of engines are those, more modern ones, with appropriate electronics and other features, however their purchase price is too high for general aviation market to be employed in large scale for 5-19 passenger turboprop aircraft or for light helicopters. In small power ranges for 2-5 passenger aircraft affordable certified turbine propulsion practically does not exist.

Market opportunity

Generally there is a worldwide growing need for efficient and environmentally friendly family of gas turbine engines with thermodynamic power range from 180 kW up to 1.0 MW. These categories of propulsion units are used to power small turboprop aircraft, light helicopters, transport utility aircraft and regional commuters.

There is also a trend in the replacement of piston engines by turbines due to many reasons for example AVGAS 100 fuel unavailability, mass and weight reduction, longer TBO maintenance time, better passenger comfort or simply lack of spare parts for older types of piston engines.

We should also mention the growing retrofit market where old types of turbine engines on currently operating aircraft are replaced by modern propulsion units. Last but not least the replacement of single piston engine on light helicopters by two light turbines can significantly increase their operational potential. Light helicopters with single engine are not allowed to land in the cities and therefore they cannot be used as an aero-taxi.

Lowering operation costs

Turboprop engines used in GA aircraft feature much longer service intervals (TBO) than reciprocating engines of similar power levels, especially as one gets into the higher power levels. Turboprops can typically go up to 5000 hours or more before their hot-sections become due for maintenance checks. Reciprocating (piston) engines used in GA aircraft typically have TBOs of 1000 to 2000 hours, with the higher horsepower models having the lower TBO numbers.

Reverse of obsolete aircraft engines (piston, old GTE types)

- **Immense operational workload for the pilot**
- **Intensive and long maintenance, repair & overhaul**
- **Spare parts limited availability for older engine types**
- **AVGAS limited availability for piston engines**
- **Lead contamination in case of AVGAS fuel**

Caused by

Out-of-date parts and engine technology

However, reciprocating engines are usually cheaper than turborpops and turboshafts – that is why they are used in smaller and lighter aircraft types. But one pays for the lower initial cost with mechanical and operational complexity that leads to much more frequent maintenance checks in case of piston engines. The currently available turboprop/turboshaft engines are not cheap, mostly due to the cost of the metal alloys used for their construction and manufacture techniques. On the other hand these engines are much simpler, easy to control and can produce large amounts of power while weighing much less than their reciprocating equivalents. Aircraft with GTE can fly higher, faster and farther than with piston engine and therefore they can be more efficient.

Increased safety and reliability

The safety and reliability of GA aircraft and its systems are also crucial conditions for their wider employment in the near future**. Turboprops are more reliable than pistons** because they have fewer moving parts. When operated and maintained properly, turbine engines are much more reliable than equivalent piston engines and they have a higher power output to weight ratio. **Two small turbines instead of one piston engine for light helicopter is a significant contribution to the helicopter safety and its extended employment in urban areas.** Nevertheless, the price reduction of gas turbine engines remains the constant challenge for engine manufacturers in order to make GTE more affordable for General Aviation.

Environmental aspects

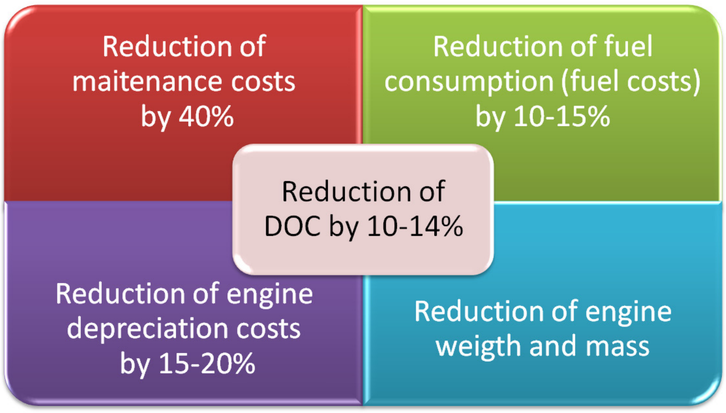
According to the Report of the UN Intergovernmental Panel on Climate Change (IPCC), general aviation (including business aviation) represents about 2% of the CO2 emissions generated by all of aviation. And the whole sector of aviation represents about 2% of the total annual man-made CO2 emissions. In short, **general aviation generates only about 0.04% of all man-made CO2 emissions,** which means negligible environmental impact.

Thanks to new turbine technologies and technological advancements such as full authority digital engine control (FADEC) a further **gas emissions decreasing is envisaged**. CO2 and NOx emission reduction belong to the ESPOSA objectives. The project will contribute to the better knowledge of emission pollution of small gas turbine engines and may contribute to the formation of the emissions standards in GA. Reduction of fuel consumption is a target of ESPOSA with regards to the air transport cost efficiency and with regards to **rationale use of fossil fuels** and will be accompanied also **by CO2 and NOx emissions reduction.**

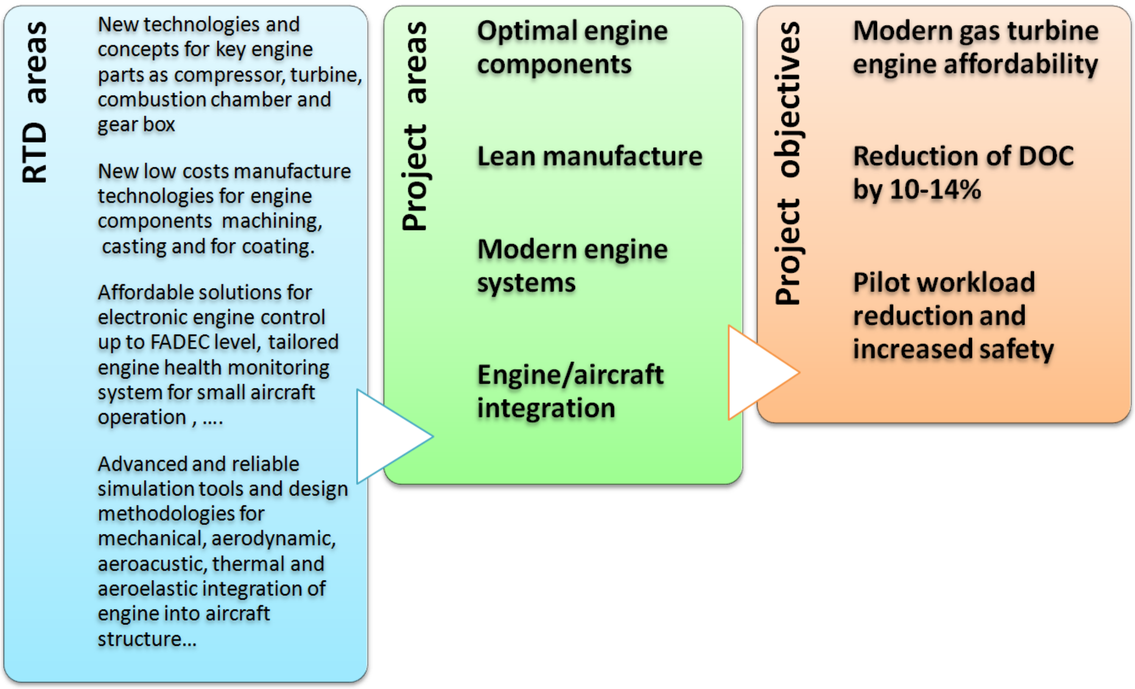
ESPOSA objectives

The ESPOSA project plans to deliver better GTE engine affordability and 10-14% reduction of direct operating costs through the development of advanced concepts for key engine components, development of lean manufacture technologies and modern engine systems improving engine overall efficiency and maintainability. The project will also deliver new or adjusted simulation and design tools and methodologies for engine integration into aircraft. The enhanced simulation capability straightens the aircraft design and saves developmental costs. ESPOSA also pioneers the smallest power range category for the turbine technology. All these can help small airplanes and helicopters to better establish themselves as a part of air transport system including also aero-taxi operation.

ESPOSA objectives for engine technologies



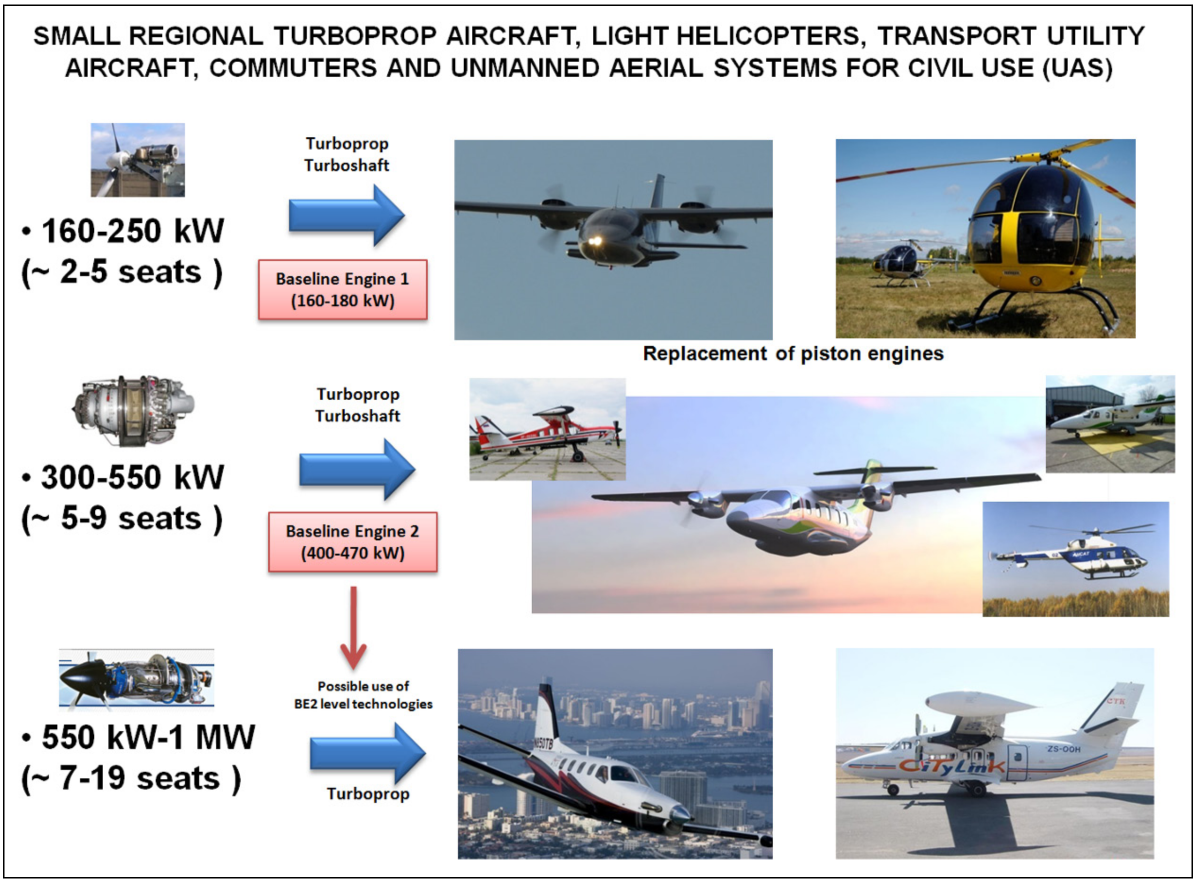
Composition of RTD and project objectives



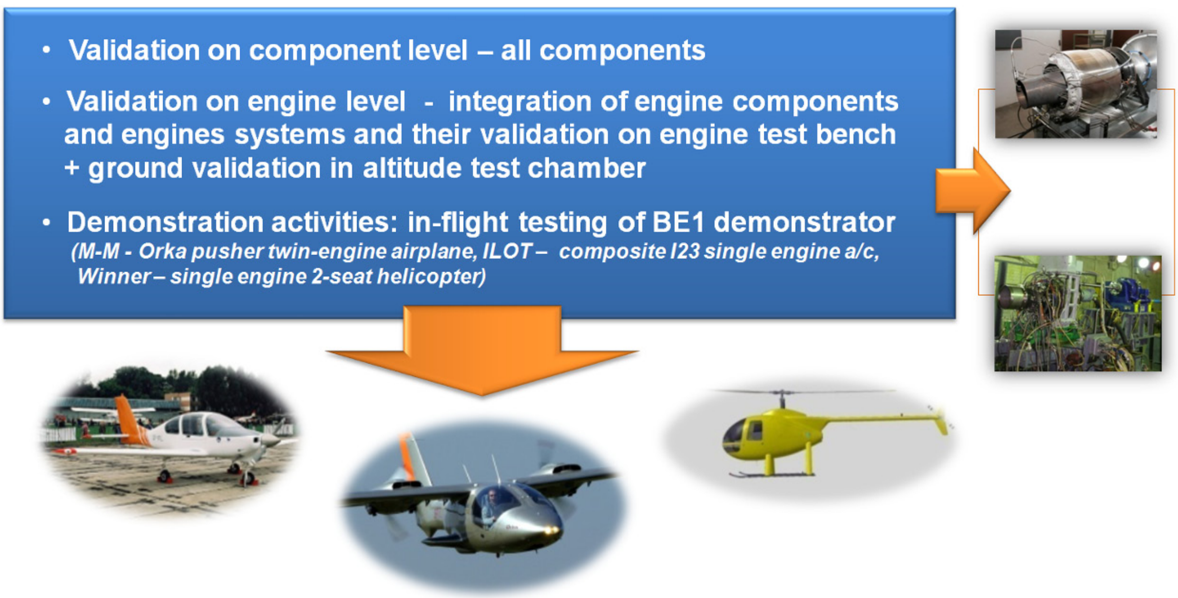
Project scope and baseline engines platforms

The following picture shows major areas of new engine technologies application and baseline engines positioning with respect to engine power categories for aircraft in CS23/FAR 23 regulations.

Applications for ESPOSA engine technologies

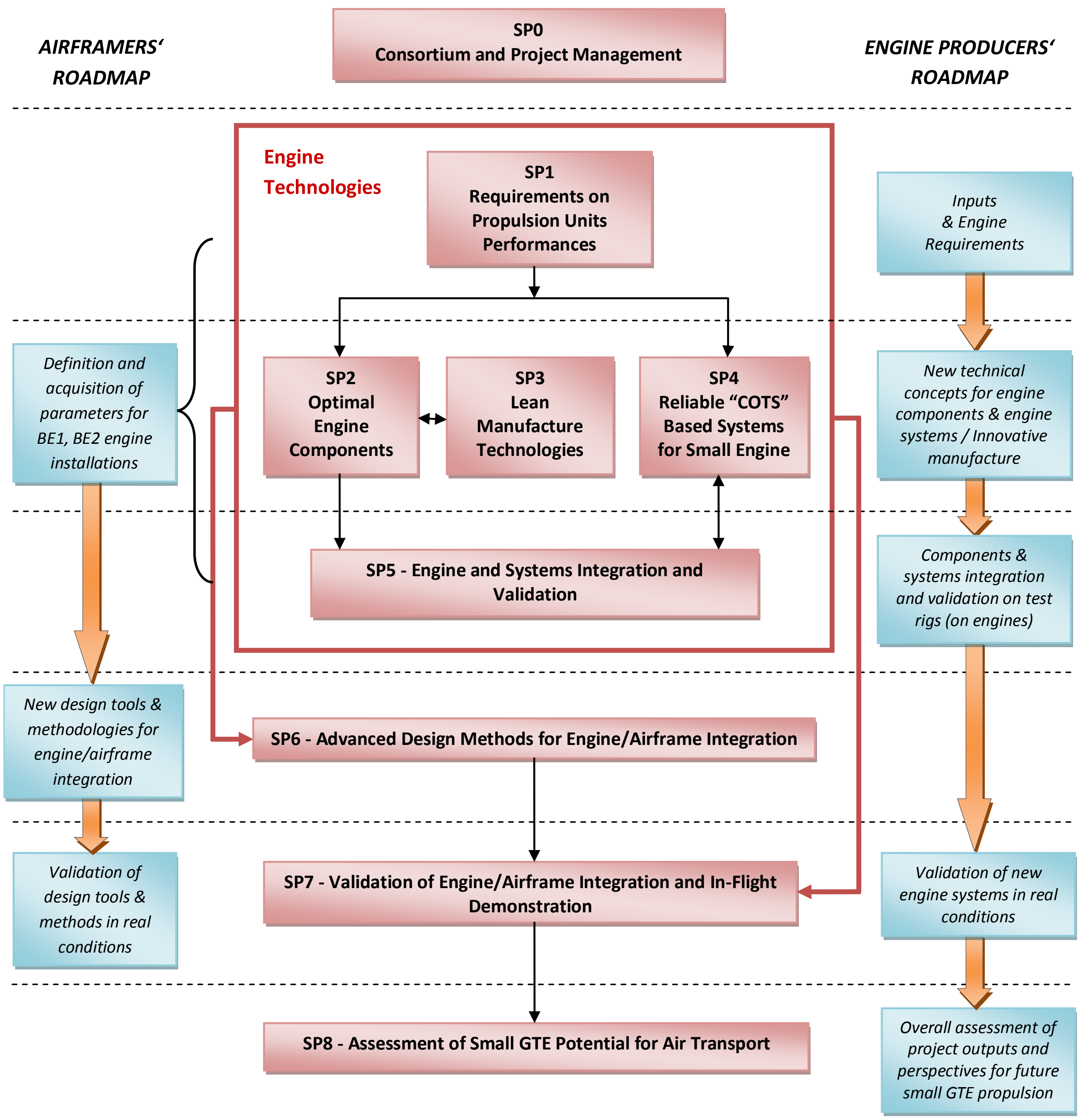


Validation and demonstration activities



Project structure and workflow

ESPOSA organizational structure and workflow



Structure of the project - sub-projects (SP) and work packages (WP)

SP 0 - Consortium and Project Management
WP 0.1 - Consortium Management
WP 0.2 - Project Technical Management
WP 0.3 - Dissemination, exploitation and IPR

SP 1 - Requirements on Propulsion Units Performances
WP 1.1 - Requirements on GTE propulsion used in General Aviation
WP 1.2 - Performance and economic specifications for baseline engines
WP 1.3 - Enhanced mathematical modelling of gas turbine engines

SP 2 - Optimal Engine Components
WP 2.1 - Optimal small compressor
WP 2.2 - Advanced low-cost small turbine
WP 2.3 - Efficient combustion concept
WP 2.4 - Optimal gear box design
WP 2.5 - Advanced dynamic modelling of high speed turbomachinery

SP 3 - Lean Manufacture Technologies
WP 3.1 - Low-cost machining for compressors
WP 3.2 - Precise and low-cost casting technologies for turbine wheels
WP 3.3 - Development of progressive coating solutions for engine parts
WP 3.4 - Low-cost gearbox manufacturing

SP 4 - Reliable "COTS" Based Systems for Small Engine
WP 4.1 - Advanced automatic control system for small engines
WP 4.2 - Smart health monitoring system
WP 4.3 - Affordable more electric solution for fuel and propeller control systems

SP 5 - Engine and Systems Integration and Validation
WP 5.1 - Validation of BE1 on test rig
WP 5.2 - Validation of BE2 on test rig
WP 5.3 - Validation of BE2 in altitude test chamber

SP 6 - Advanced Design Methods for Engine/Airframe Integration
WP 6.1 - Complex design methodology for engine mechanical integration
WP 6.2 - Reliable design methodology for aerodynamic engine/airframe integration
WP 6.3 - Tools for engine and nacelle aeroelastic integration – "Whirl Flutter"
WP 6.4 - Reliable simulation tools for engine thermal integration
WP 6.5 - New design and manufacturing approaches for "hot" composite nacelles

SP 7 - Validation of Engine /Airframe Integration and In-Flight Demonstration
WP 7.1 - Validation of integration design methodologies
WP 7.2 - Qualification activities for flight testing
WP 7.3 - Overall demonstration in In-flight conditions

SP 8 - Assessment of Small GTE Potential for Air Transport
WP 8.1 - Future engines architectures
WP 8.2 - Overall assessment of SP results toward ESPOSA objectives

Summary of ESPOSA new technologies and innovative solutions

Technology area **New technologies, innovative solutions**

Optimal engine components

- Design concept and technology solutions for high pressure centrifugal compressor (adiabatic efficiency will be no less than 0.82, a total pressure ratio 9.5)
- Optimized compressor (engine) inlet design solutions to provide higher propulsive system efficiency and safety centrifugal compressor surge control (surge margin)
- Development of advanced casing treatments and mechanical active clearance control for centrifugal compressor
- Design concept and technology solutions for cooled turbine with high level of efficiency (0.84), high inlet turbine temperature level (1430-1500K), high reliability, and low weight (-10%) and higher propulsive system efficiency (+7%)
- New simple cooling technology based on cooling film from a slot at the leading edge on the vane forming a thermal barrier covering the complete vane surface will be developed for vanes of small turbines to prolong their lifetime
- New alternative combustion JETIS (JET Induced Swirl) concept will be investigated and validated
- New tools for mesh excitation modelling for optimal gearbox design concept and noise emissions prediction
- Development of an advanced rotordynamic model of a GTE rotor system
- Development of a propeller dynamic model methodology used for investigation of coupled propeller and engine vibration models
- Improved Gasturbine Simulation Program (GSP) for enhanced GTE modelling of dynamic behaviour of the whole engine system
- New innovative architectures for future small aircraft engines including advanced bypass and open-rotor engines and their technological and economic assessment

Contribution to the measurable project objectives:

- ✓ Component design solutions aimed at low-cost production – better GTE affordability
- ✓ Reduction of fuel costs by 10-15% (part of this objective will be achieved through the optimal component, the second part through the new engine control systems)
- ✓ Contribution to the component lifetime increase (MRO costs reduction)
- ✓ Weight reduction contributes to the overall aircraft efficiency
- ✓ Enhanced tool for GTE modelling facilitates engine development process
- ✓ New innovative engine architectures can serve as technology roadmap for the development of next generation of modern engine

Technology area **New technologies, innovative solutions**

Lean manufacture

- Newly optimized machining strategies to reduce machining time and cost of the most labour-intensive centrifugal compressor parts, such as impeller and diffuser, (improved high-speed multi-axis machining of aviation materials)
- New manufacture technologies for effective casting of turbine wheels of small power class engines incl. enhanced numerical simulation for better quality control and for reduction of scrap rate by 10% a reduction of part price by 8%
- Investigation of new high temperature materials for turbine wheels casting, use of new nickel based super alloys with higher heat corrosion and heat resistant characteristic about 1050°C
- Development of new thermal barrier coating based on new nanostructured zirconia materials for TBC deposition and on HFPD (high frequency pulse detonation) technology, in order to deposit dense, erosion resistant and high performance zirconia top coats in single and/or multilayered structures
- Development of novel thermal spray processes based on the HFPD and a new hybrid high velocity combustion (OFI, from Oxy-Fuel Ionisation) spray technologies
- Development of novel composite materials for compressor blade roots to replace existing CuNiIn coatings based on blends of HT corrosion resistant cobalt alloys and solid lubricants such as Hexagonal Boron Nitride (hBN).
- Development of novel ceramic materials for TBC applications under extreme service conditions with optimised architecture in the nano-scale
- New manufacture technologies for improvement of finishing processes of transmission elements of gearbox wheels as the most time consuming operations
- New manufacture technologies for reduction of energy consumption during the heat treatment and quenching using the CIH contour induction hardening process for gearbox wheels
- New manufacture technologies for reduction of the machining time for gearbox wheels (superfinishing, honing by red ring, honing) by faster and precise grinding

<u>Contribution to the measurable project objectives:</u>

- ✓ New manufacture technologies aimed at low-cost production – better GTE affordability
- ✓ New manufacture technologies and procedures for significant reduction of leading time and the scrap rate

Technology area **New technologies, innovative solutions**

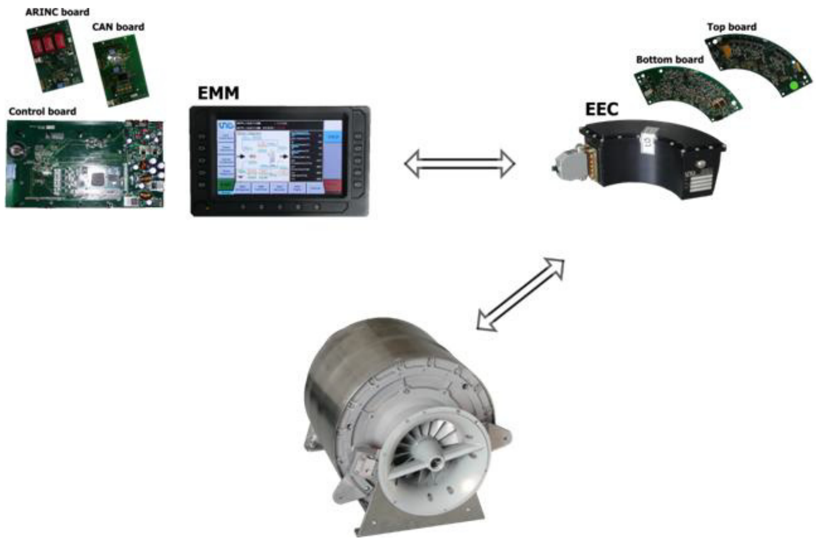
Modern engine systems

- New technologies for EEC/FADEC using COTS-based HW/SW control components, MEMS technology for energy harvesting and scavenging, wireless sensors, reusable HW/SW components and embedded reliable real time operation systems (RTOS)
- New technologies and components for smart health monitoring system (HUMS "light") based on wireless sensor network (WSN)
- New affordable technologies for decentralized solutions for fuel and propeller control systems with novel electric actuation systems and integrated electronics with the self diagnostics tools and back-up algorithm (novel heat resistant control system of Brushless BLDC motors)

Contribution to the measurable project objectives:

- ✓ Reduction of engine fuel consumption by 4-8 % and a consequent decrease of aircraft operating costs (together with new engine components 10-15% reduction)
- ✓ Reduction of pilot workload by 10-20% using electronic engine control
- ✓ Wireless sensor network reduces the weight by 15-30 kg per small aircraft and reduces the installation time from 3-4 days to 1 day
- ✓ Smart health monitoring for small engines can be a significant source for TBO a the whole engine life prolongation and maintenance costs reduction
- ✓ Use of more-electric oil/fuel system can reduce the weight of the system by 10%

Illustrative example of embedded Engine health monitoring system(EHM) and Electronic Engine Control (EEC) for small jet turbine



Technology area	New technologies, innovative solutions

Engine/airframe integration

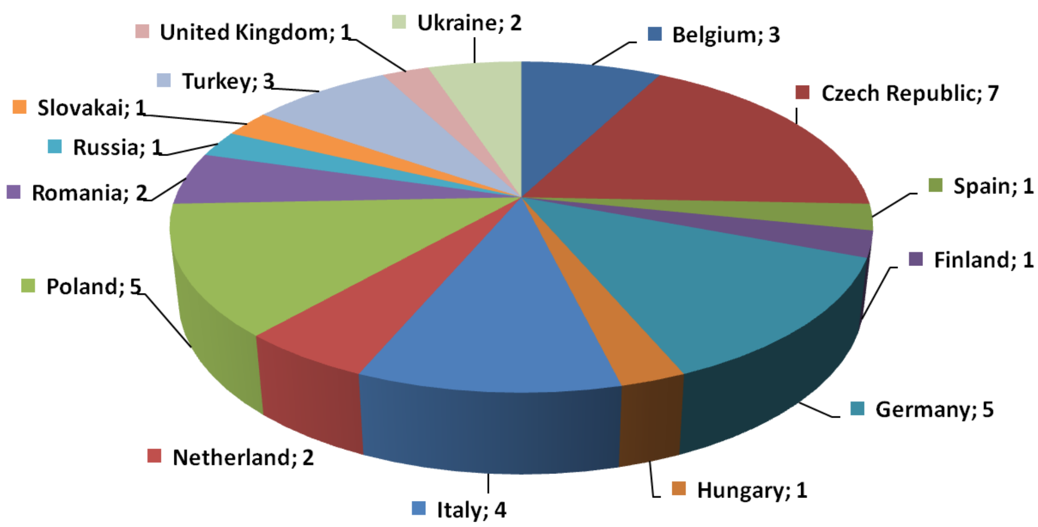
- ➢ Multidisciplinary design tool solutions for issues connected with engine mechanical integration, aerodynamic drag aspects and thermal management connected with GTE engine installation/integration into aircraft
- ✓ Design methodology (a guide for designers) for optimal GTE unit installation respecting very complex requirements
- ➢ Study of configuration aerodynamic impact on propulsion performances
- ➢ Innovative aerodynamic design methodologies for air inlet and internal nacelle duct including solid particle separators, study on potential of vortex generators aerodynamic employment in internal ducts
- ➢ Innovative aerodynamic design methodologies for nacelle external shape – improved methods and design procedures
- ➢ New methodologies for the assessment of propeller slipstream effect of small aircraft of different configurations
- ➢ Development of improved techniques and tools used for the whirl flutter analysis
- ➢ Development of novel models, tools, and optimizations methods that will allow more efficient and more accurate aero-thermal design and assessments with respect to the engine thermal integration and nacelle design. (heat exchanger (engine oil cooler, generator cooler) system design; nacelle case ventilation; exhaust plume design optimization
- ➢ New design knowledge and the development of complex design methodology for heat resistance composites for nacelles (Liquid Moulding-infusion, Quick-Step and Out-of-autoclave prepregs)

<u>Contribution to the measurable project objectives:</u>

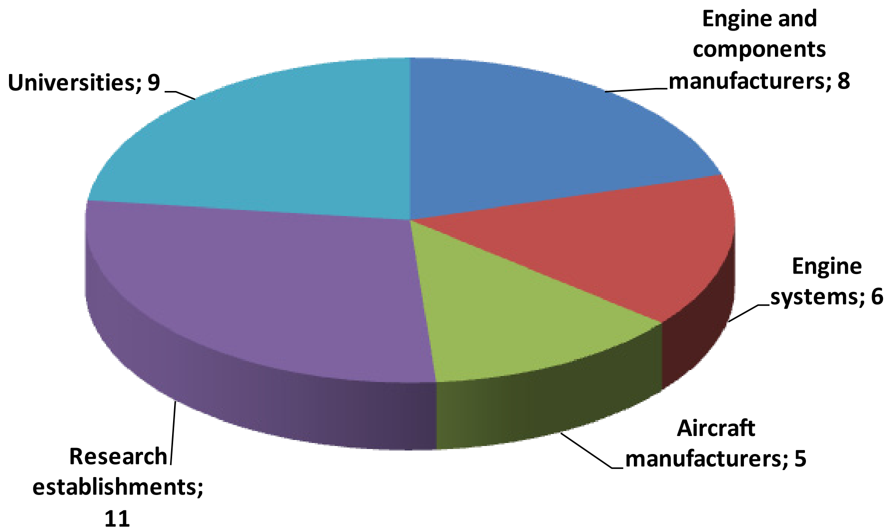
- ✓ Reduction of development time and costs (reduction of iterations)
- ✓ Reduction of the costs and time in certification process (whirl flutter tool)
- ✓ Weight reduction – hot composites for nacelles

ESPOSA Consortium

The ESPOSA consortium consists of 39 participating organizations having high expertise in different fields. Companies and research organizations having appropriate competence were invited to participate in the ESPOSA project. The key element for their participation is their willingness to devote their research and technological effort to small aircraft sector. A very good balance between stable industrial companies and renowned research organizations gives the ESPOSA project high potential for planned research and technology developmental work. **Ten partners (26%) belong to the SMEs. The budget of SMEs** involved in ESPOSA is close to **8 mil. EUR**, representing nearly **19%** of the total planned budget (42,4 mil EUR). **The consortium comprises 15 European nations.**



ESPOSA consortium according to the type of organization



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