Łukasiewicz Instytut Lotnictwa

CLEAN AVIATION

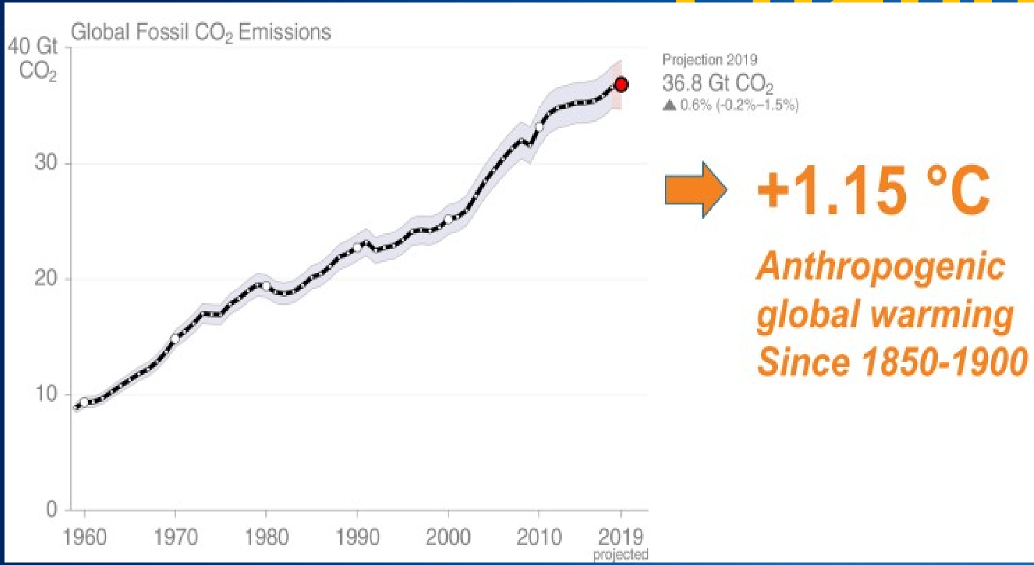
EFACA Environmentally Friendly Aviation for all Classes of Aircraft

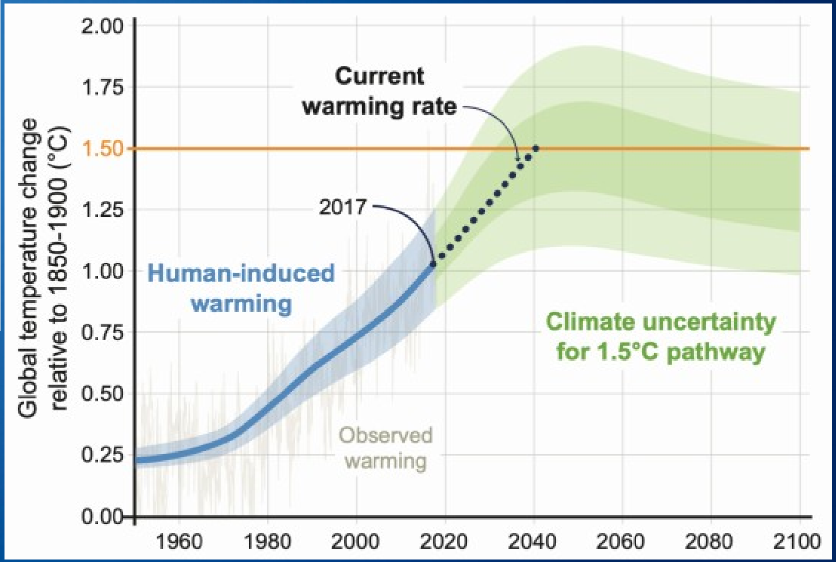
Clean aviation program in Europe
- towards energy efficient and climate neutral aviation

Dr. Oleksandr ZAPOROZHETS
Professor at Institute of Aviation (Łukasiewicz Research Network – Institute of Aviation), Warsaw, Poland

This activity is supported by: The NATO Science for Peace and Security Programme

Global Emission & Climate Changes





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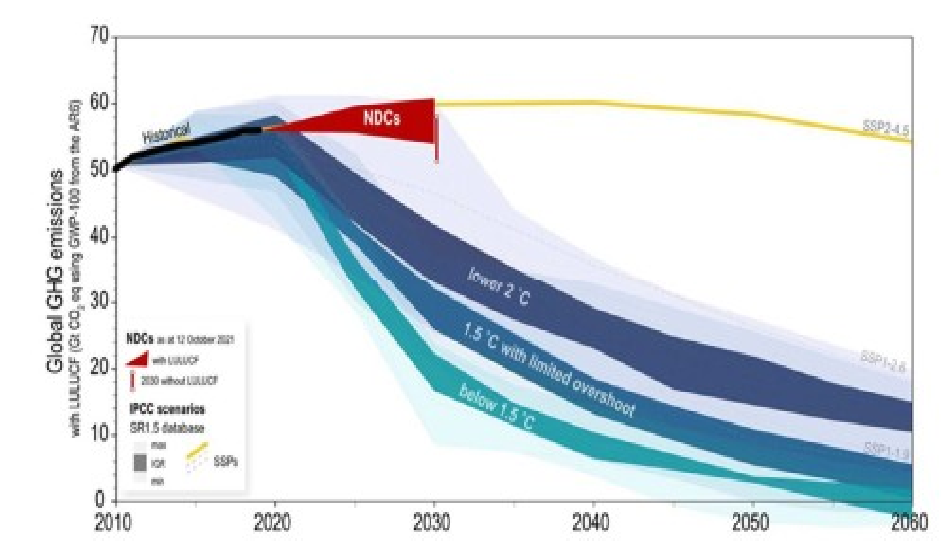
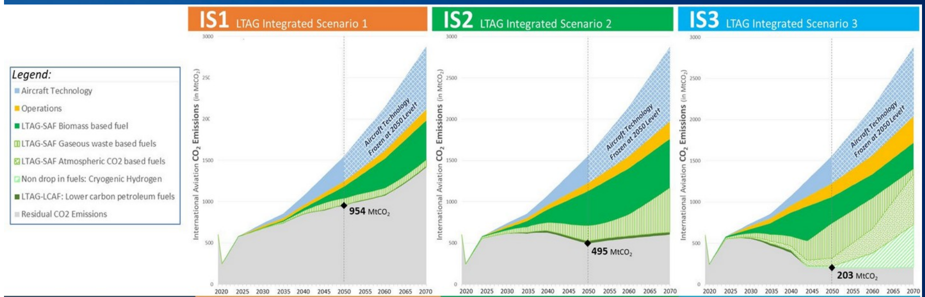
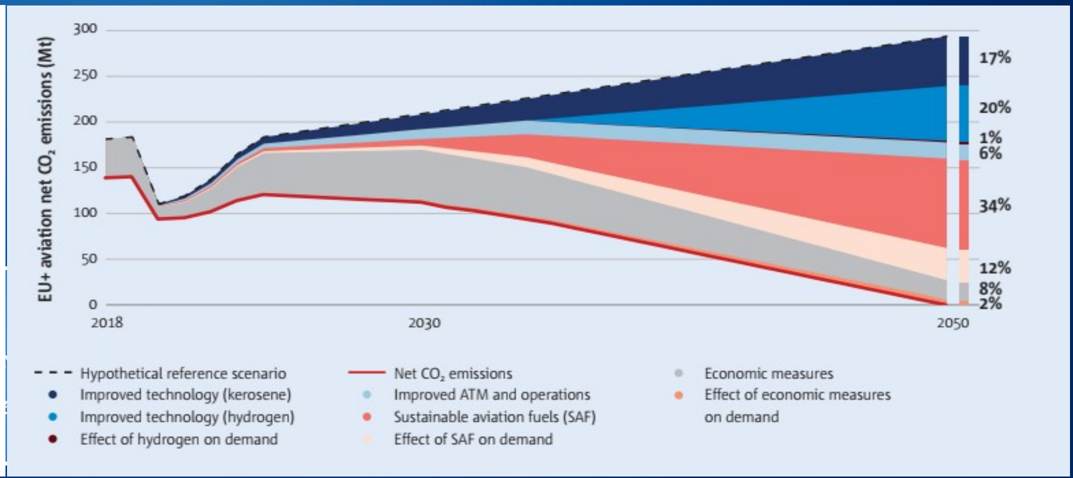


IPCC –ICAO



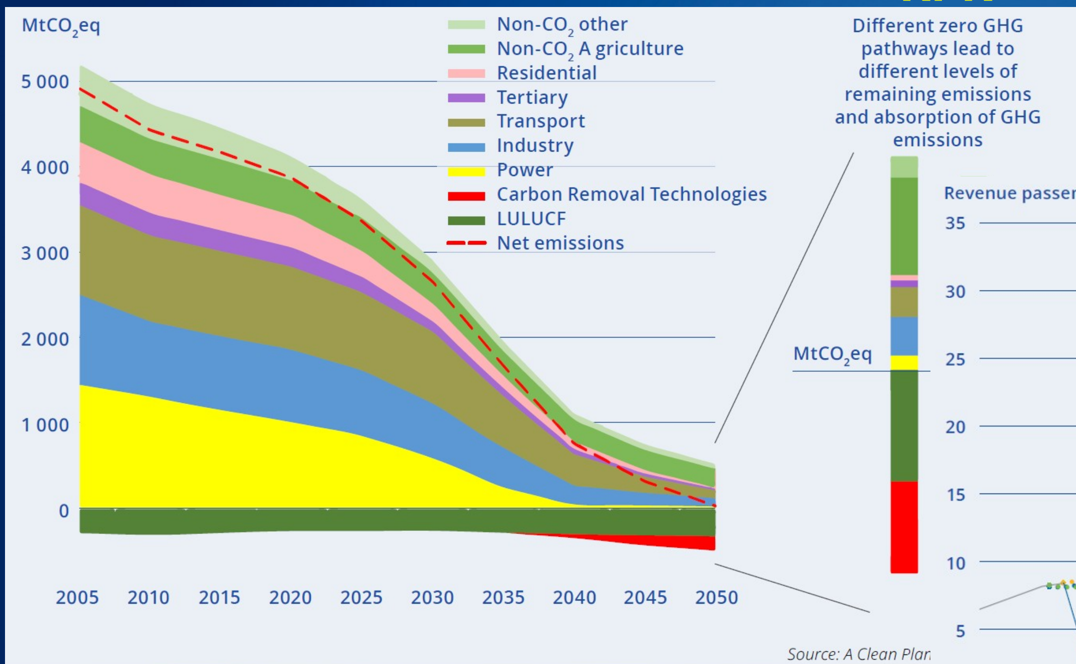
Metrics	IS1	IS2	IS3
CO_2 Emissions in 2050 after Reductions	≈950 MtCO$_2$ in 2050 *(160% of 2019 CO_2 emissions)*	≈500 MtCO$_2$ in 2050 *(80% of 2019 CO_2 emissions)*	≈200 MtCO$_2$ in 2050 *(35% of 2019 CO_2 emissions)*
Reduction in 2050 from the Baseline	**39% total** through: Technologies - 20%, Operations - 4%, Fuels - 15%	**68% total** through: Technologies - 21%, Operations - 6%, Fuels - 41%)	**87% total** through: Technologies - 21%, Operations - 11%, Fuels - 55%
Cumulative residual Emissions from 2020 to 2070	23 GtCO$_2$ (2020 to 2050) 23 GtCO$_2$ (2051 to 2070)	17 GtCO$_2$ (2020 to 2050) 11 GtCO$_2$ (2051 to 2070)	12 GtCO$_2$ (2020 to 2050) 4 GtCO$_2$ (2051 to 2070)

EU Green Deal–Destination 2050



The global and European context

Europe’s GHG emissions trajectory in a 1.5°C scenario & EU aviation sector RPK



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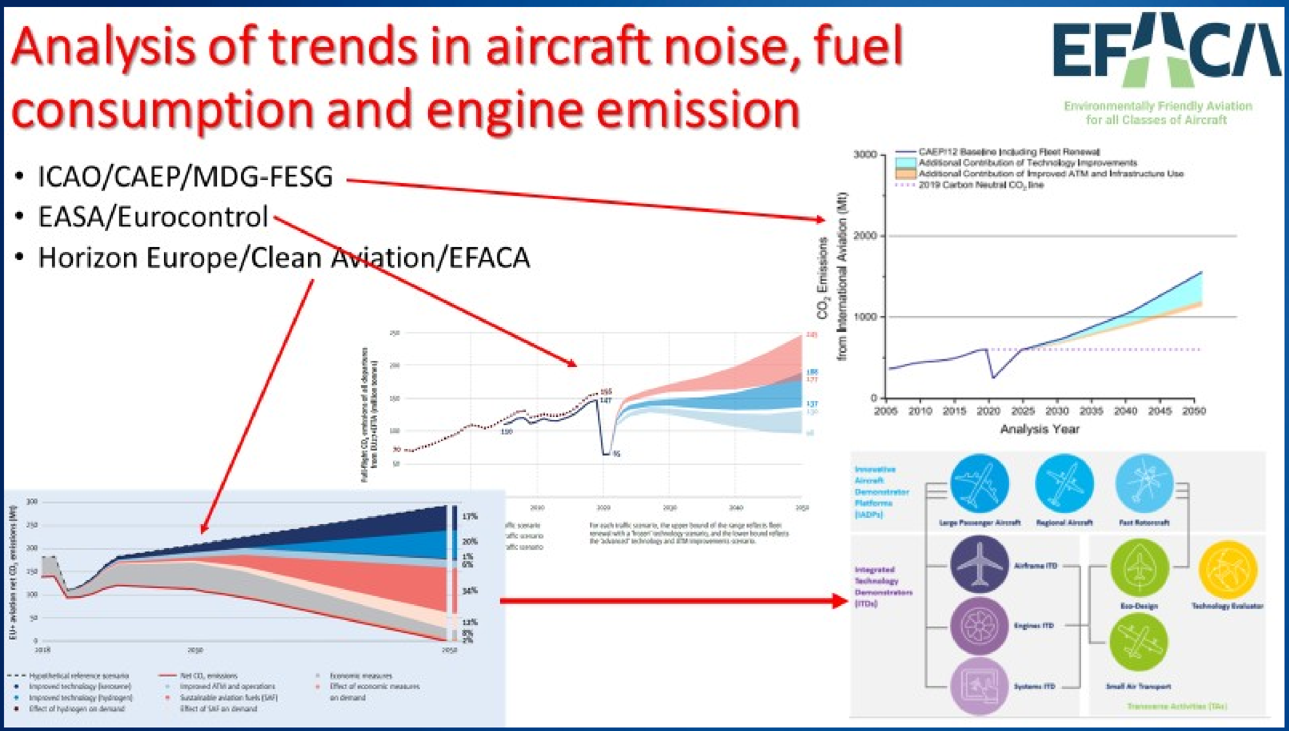
Decomposition of the main goal of current research



- **Global emission and fossil fuel burn reduction** – main goal
- Local air quality - goal
- Aircraft noise - goal
- Aircraft sources of impact
- Technologies of impact reduction

- Aircraft level
- Airport level
- Global/regional fleet level

The horizons in the trajectory towards climate-neutral aviation

FOSSIL FUEL BASED AVIATION	LOW CARBON AVIATION	CLIMATE NEUTRAL AVIATION
LONG RANGE SHORT/MEDIUM RANGE REGIONAL COMMUTERS HELICOPTERS	Ultra-efficient aircraft + increased use of sustainable alternative fuels Small electric aircraft Hybrid regional and short range aircraft New hydrogen powered aircraft New short distance mobility	Hyper-efficient aircraft Fully decarbonized energy sources, i.e. alternative zero (net) emissions fuels/energy carriers e.g. > Liquid H2 > Power to Liquid fuels > Ultra-high density batteries and/or fuel cells
	Green aircraft operations and infrastructures	Climate neutral aircraft operations and infrastructures
	Green aircraft regulations	Climate neutral aircraft regulations

HORIZON EUROPE

2030 2040 2050

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“Capacity Building for a New Generation of Scientists in Energy Security and Climate Neutrality”
Advanced Study Institute, Budapest, October 8-16, 2024

GÉPIPARI TUDOMÁNYOS EGYESÜLET

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CAEP IEP Technology Taxonomy

Fuel Burn — METRIC

DOMAIN: Propulsion | Structures/Materials | Aerodynamics / Flight Physics | Systems & Integration | Advanced Configurations

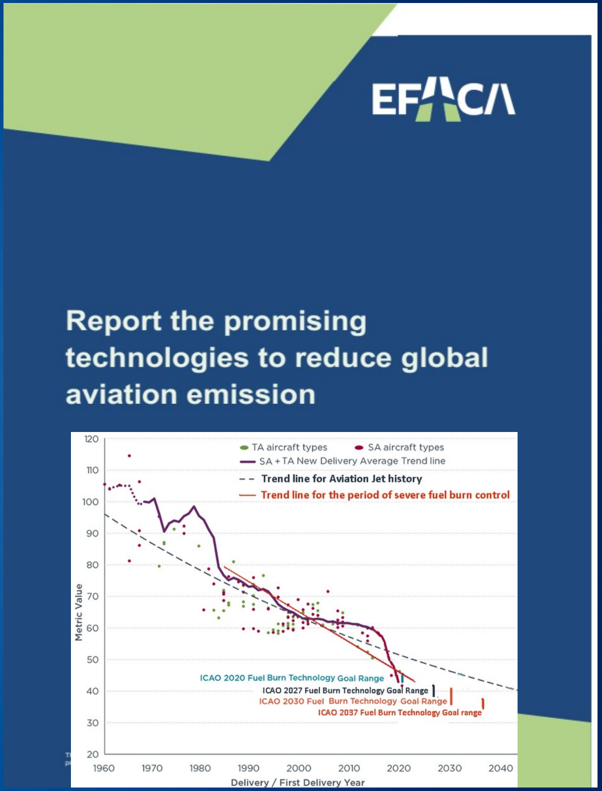
CATEGORY:
- Propulsion: Propulsive Efficiency [FPR, Component Efficiencies]; Thermal Efficiency [OPR, TET]
- Structures/Materials: Advanced Composite Technology [% Weight]; Advanced Metallic Technology [% Weight]; Optimized Local Design [% Weight]
- Aerodynamics / Flight Physics: Viscous Drag [% CD_o]; Induced Drag / Wave Drag [% CD_i]
- Systems & Integration: Advanced Controls [% Fuel Burn]; Mission Optimization Methods [% Fuel Burn]
- Advanced Configurations: Configuration Change [% Fuel Burn]

Advanced Turbofan
UHBR Ducted Propulsor / GTF
Contra Fan
Open Rotor
BLI Aft-Fuselage Propulsion

Emissions — METRIC

CATEGORY: LTO NOx Emissions Improvements (% NOx Reduction) | Cruise NOx Emissions Improvements (% NOx Reduction) | nvPM Improvements (% nvPM Reduction)

Technologies *Examples – Not an exhaustive list*:
- Advanced Rich Quench Lean
- Advanced Lean (LEAP X, RR)
- Advanced Single Annular Combustor (i.e. SABER, TALON X, RR)
- Advanced Lean-Staged
- Axially Controlled Stoichiometry (ACS) Combustor
- High-Shear Swirler / Fuel Injectors
- Advanced Impingement Film Floatwall
- Twin Annular Pre-Mixed Swirler
- Advanced Fuel Spray Nozzles
- Highly Efficient Wall Cooling
- CMC Combustor Liners
- Active-Combustion Control
- Lean Direct Injection (LDI)



Seat category	Aircraft Category	2010 reference	New generation (examples)	Entry into service	Fuel saving reference
51 – 100	Regional jet	ATR/CRJ	ATR-72-500/600	2020	20%
		E-Jet	E-Jet E2 A220-300	2020	24%
101 – 210	Narrow body	A320/B737	A220-300/A320neo/B737 MAX	2016/2017	20%
211 – 300	Wide body	B767	A350/B787	2015/2011	20%–25%
301 – 400		A330/B777	A330neo/B777X	2018/2019	14%–20%
401 – 500		A380/B747-8	A330neo/B777X	2018/2019	14%–20%

Meeting 11 September 20

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Mapping of the research thrusts against aircraft categories and concepts

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DISRUPTIVE TECHNOLOGIES FOR ULTRA EFFICIENT REGIONAL AIRCRAFT

DISRUPTIVE TECHNOLOGIES FOR ULTRA EFFICIENT SHORT AND MEDIUM RANGE AIRCRAFT

DISRUPTIVE TECHNOLOGIES TO ENABLE HYDROGEN-POWERED AIRCRAFT

Low Emission Hybrid-Electric **Regional** Aircraft

Low Emission **Short / Medium Range** Aircraft

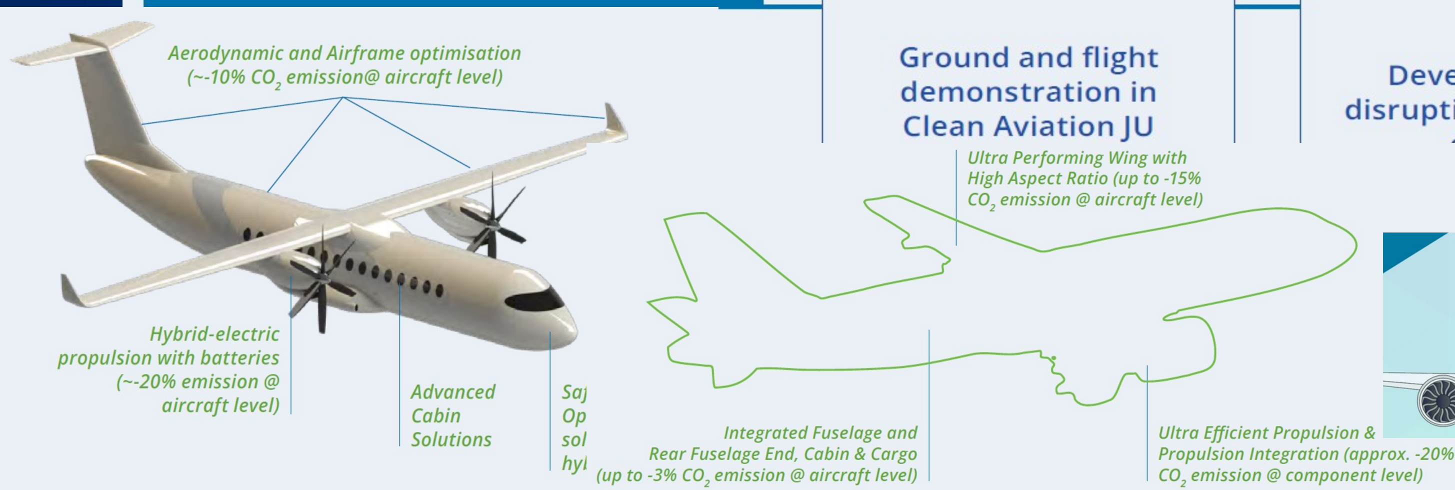
Disruptive Zero Carbon **Hydrogen-powered** Aircraft

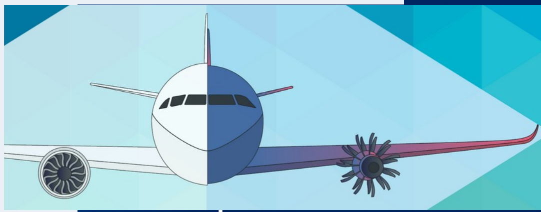
Ground and flight demonstration in Clean Aviation JU

Long Range Aircraft Concepts progressing towards climate neutrality

Zero-Carbon Hydrogen-powered **Short & Medium Range** Aircraft

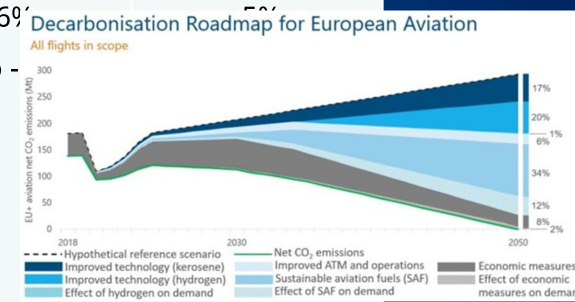
Development of disruptive technology options





Clean Aviation aircraft category targets

Aircraft Category	Key technologies and architectures to be validated at aircraft level in roadmaps	Entry Into Service Feasibility	CO_2 Emissions reduction (technology based)28	Net CO_2 Emissions reduction (i.e. including SAF effect)29	Current share of air transport system emissions
Regional	> Hybrid-electric (SAF + Batteries) coupled with highly efficient aircraft configuration > Same with H2-electric power injection (Fuel Cells electric generation)	~2035 Beyond 2035	-30% Up to -50%	-86% Up to -	5%
Short-Medium Range Commercial	Advanced ultra-efficient aircraft configuration and ultra-efficient gas turbine engines	~2035	-30%	-86%	~50%
	Full hydrogen-powered aircraft (H2 Fuel Cells or	~2035	-100%	N/A	



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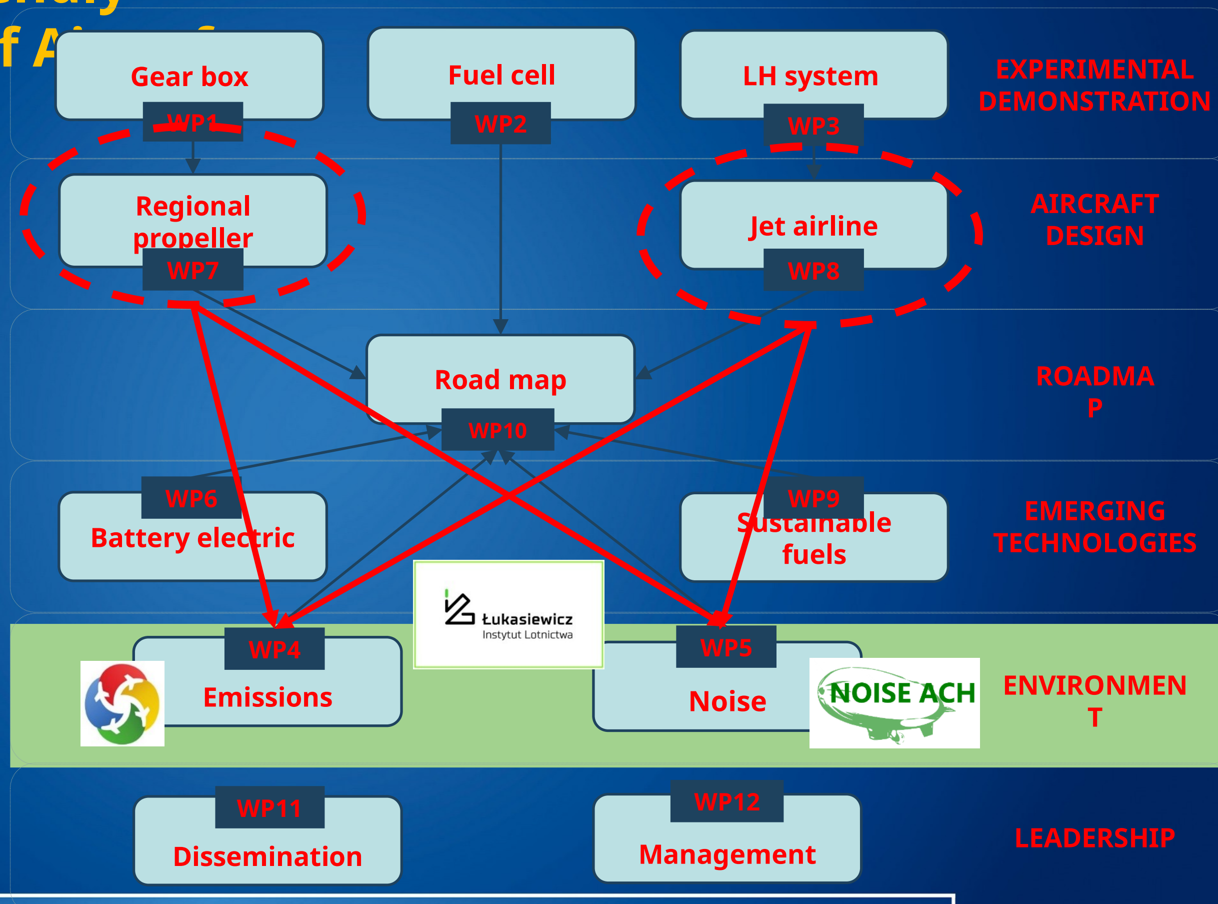
Project organizational structure



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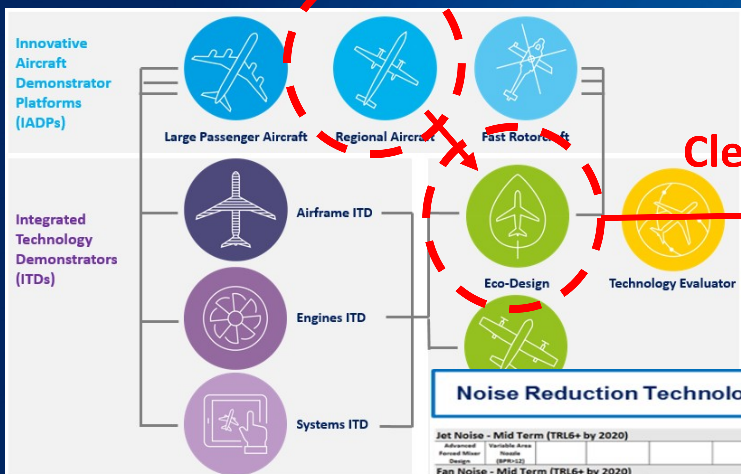
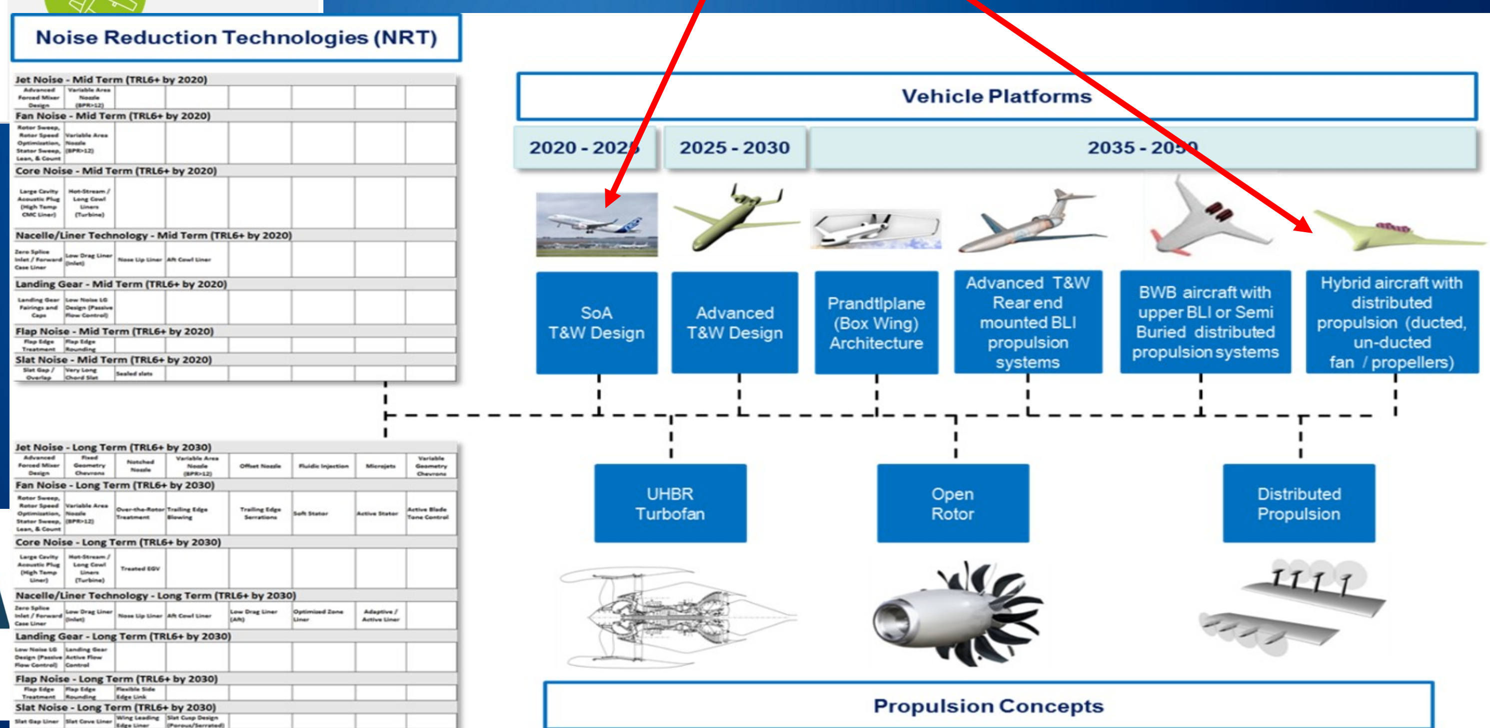
ANIMA/XNoise Technology matrix

XNoise -> ANIMA -> PULSAR -> EFACA

Clean Sky 2 – EFACA (ILOT/CEPA/NOISE) Technology Evaluator





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Modular approach to evaluation of emission and noise metrics

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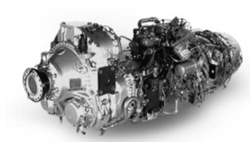
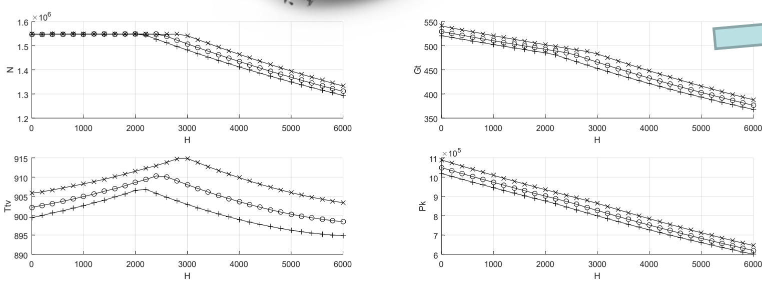
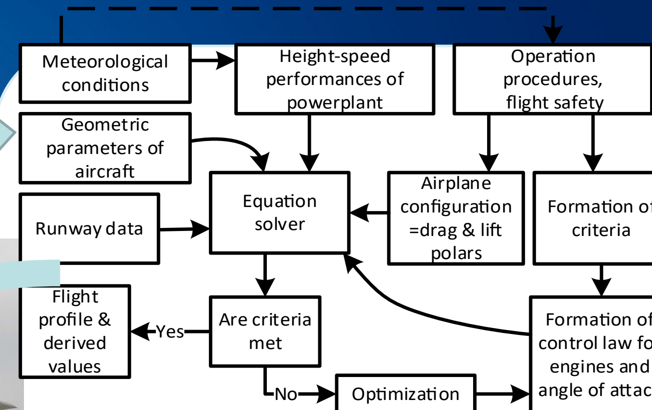


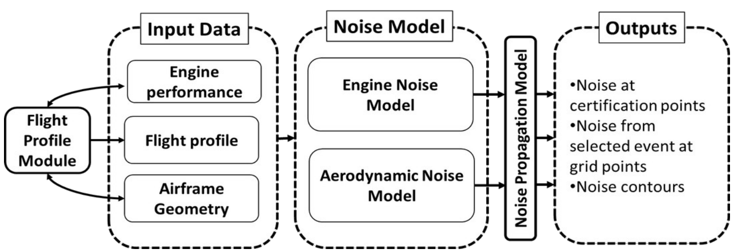


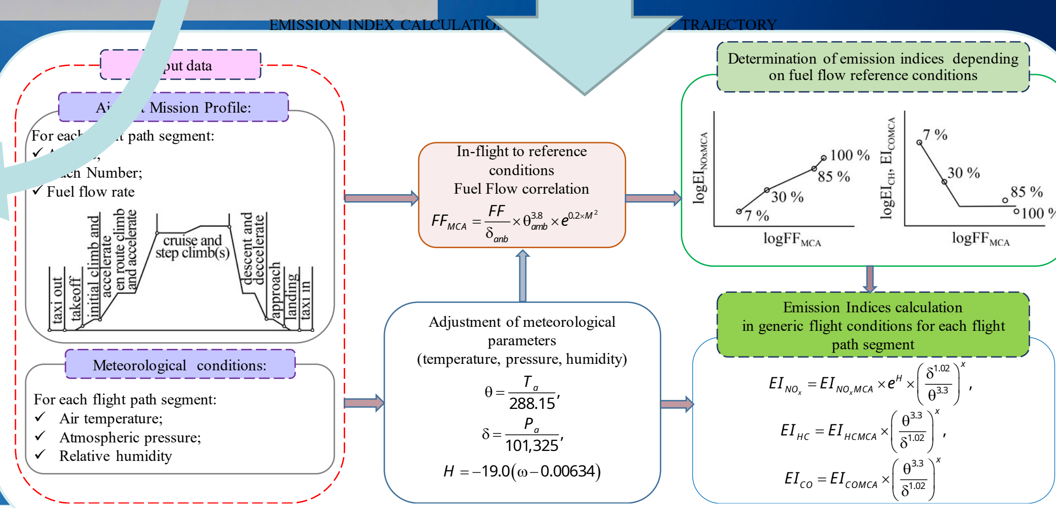
Module of working process of gas-turbine engine



Aircraft flight profile calculation module

Module for assessing noise from an aircraft with traditional and hybrid powerplant





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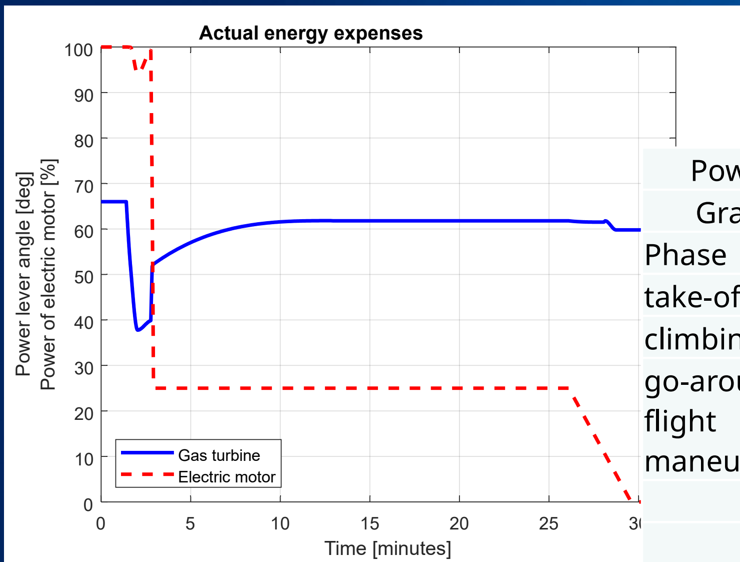


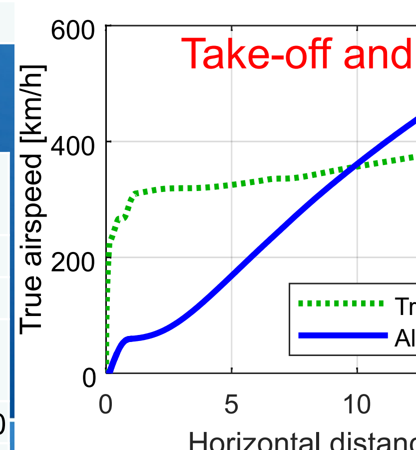
Making ATR72-500 hybrid

Planned energy expenses for one flight

Power of electric motor [kW]			500				
Gravimetric density kWh/kg			0.8				
Phase	seconds	hours	minutes	kW	kWh	%	Qty eng
take-off	90	0.025	1.5	500	25	100	2
climbing	870	0.241667	14.5	250	120.8333	50	2
go-around flight maneuver	360	0.1	6	475	47.5	95	1
		Total energy onboard, kWh			193.3333		

Mass balance of hybrid aircraft

		Total for aircraft
Installed engine weight factor	1.39	
Number of engines	2	
Electric motor power density, kW/kg	4	
	Mass [kg]	
Electric motor	-125	-250
Installed engine weight of new gas-turbine	476.631	383.362
Installed engine weight of PW127F	668.312	
Batteries		-241.667
Modernization of powerplant for hybrid,		



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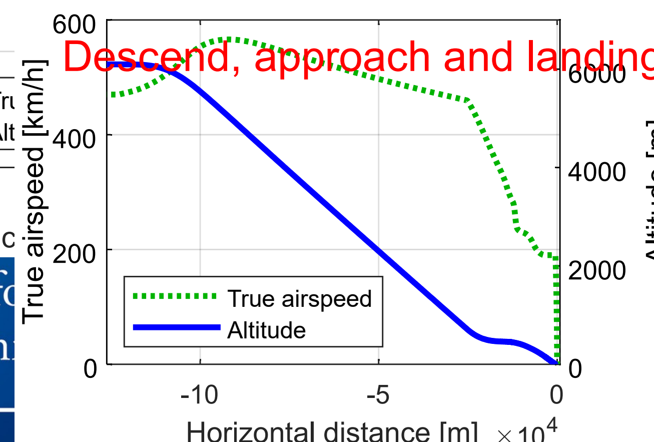
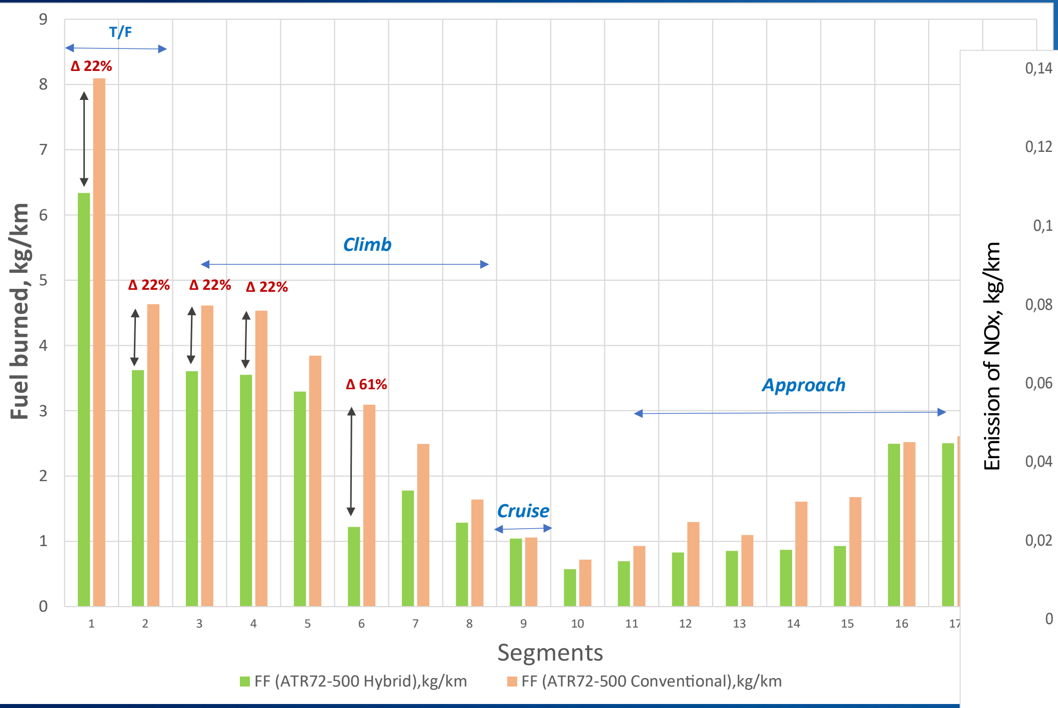
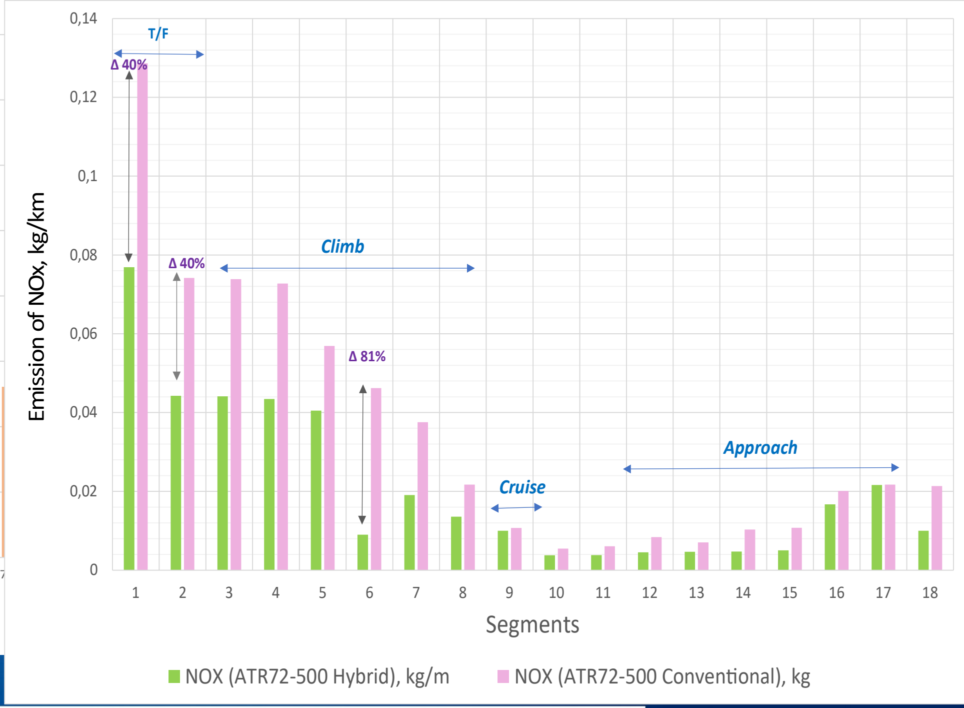


Mass of fuel burned and NOx per segment of trajectory for ATR72-600 (conventional and hybrid)





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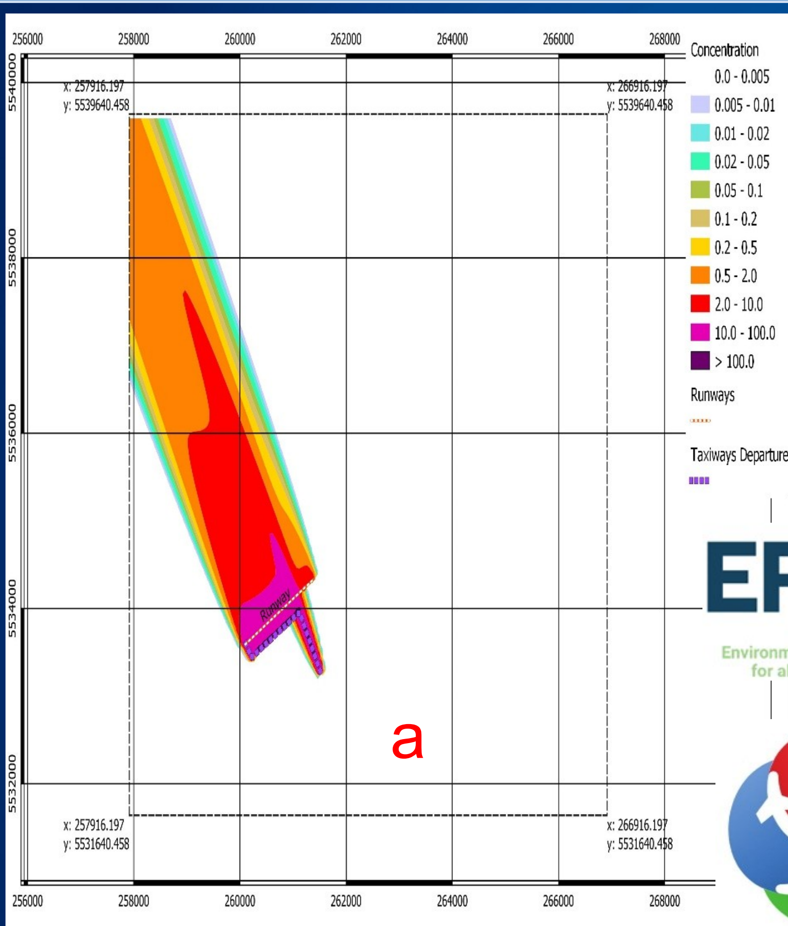

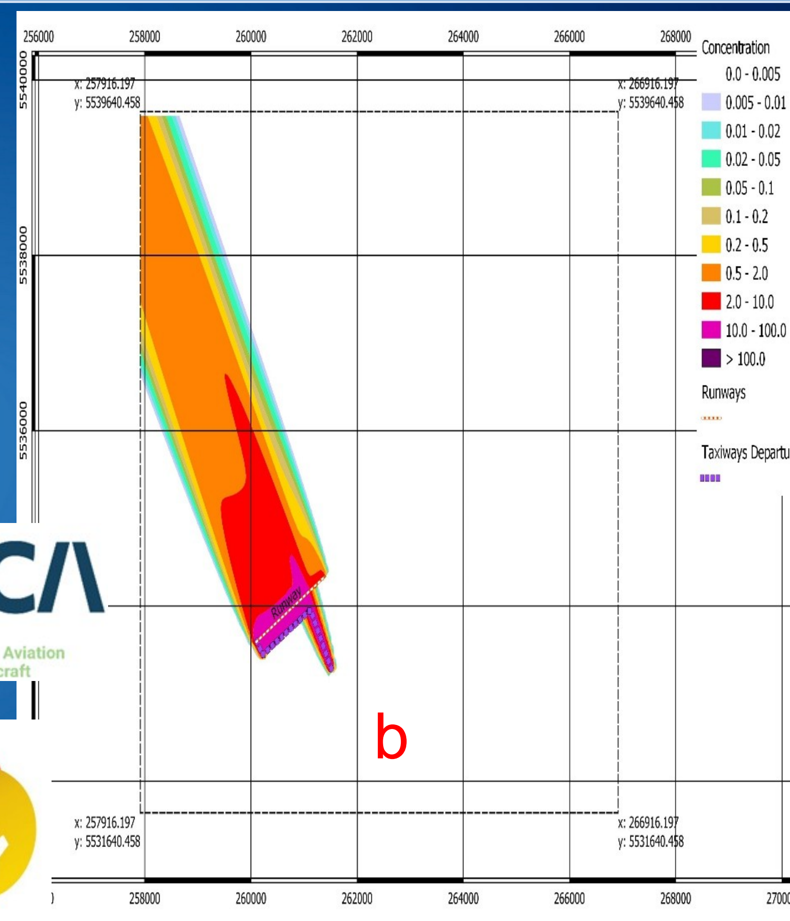

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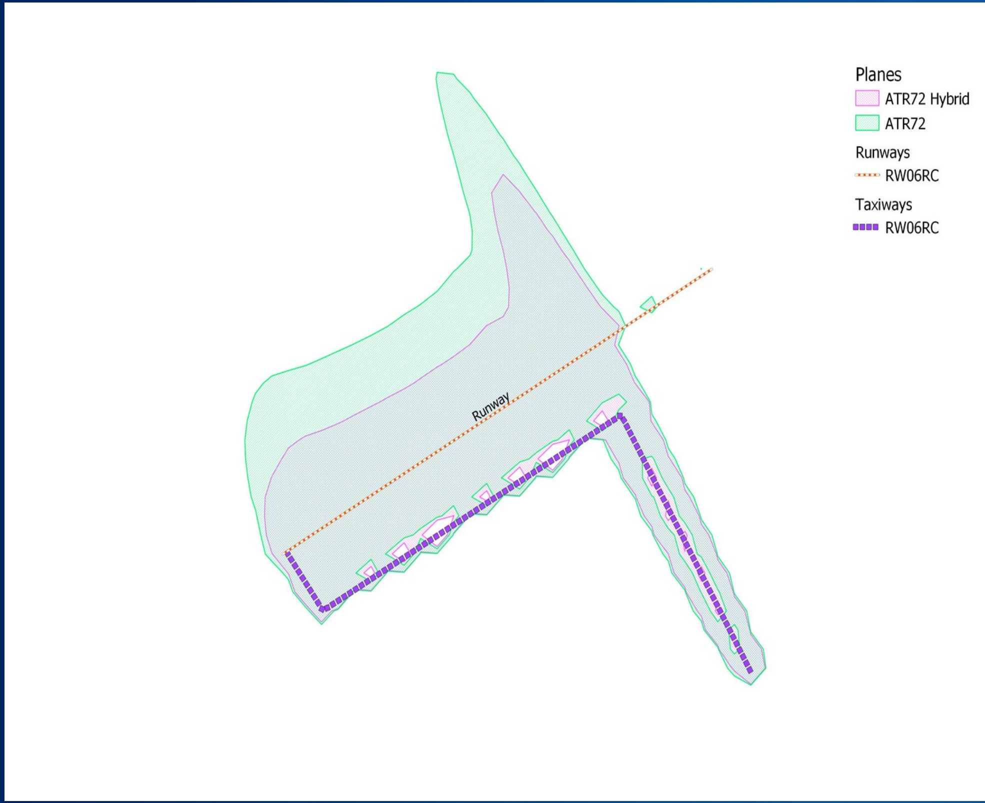
Hourly concentration of NOx for LTO-cycle conventional and hybrid ATR72-500

Area of LAQ influence



Area of NOx influence
for conventional and hybrid ATR72-500

concentration range: 10-100 µg/m3

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Airport Emission Inventory

- Turboprop (TP)
- Regional Jet (RJ)
- Small Single Aisle (SSA)
- Large Single Aisle (LSA)
- Large Twin Aisle (LTA
- Very Large Aircraft (V

Handling

- Aircraft APU
- Ground Power Unit
- Ground Support equipment

Infrastructure

- Power Plant
- Fuel Farm
- Engine test run

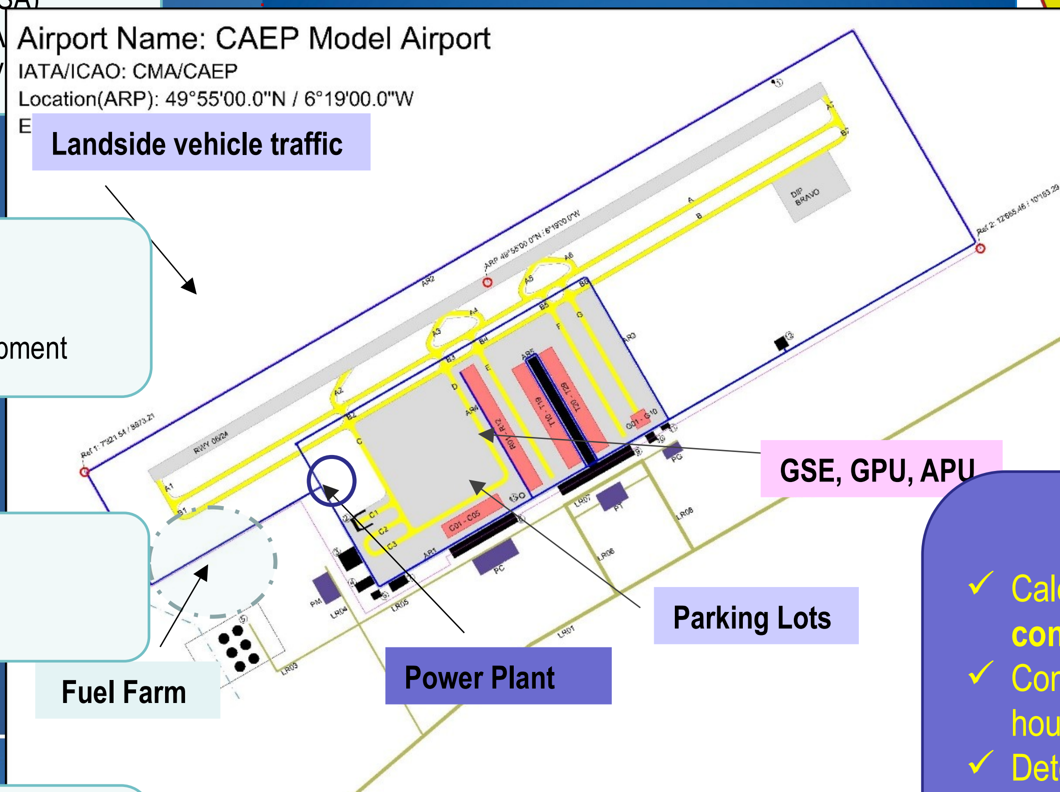
Landside Traffic

- Airside vehicle traffic
- Landside vehicle traffic
- Parking Lots

Reference Airport Scenario

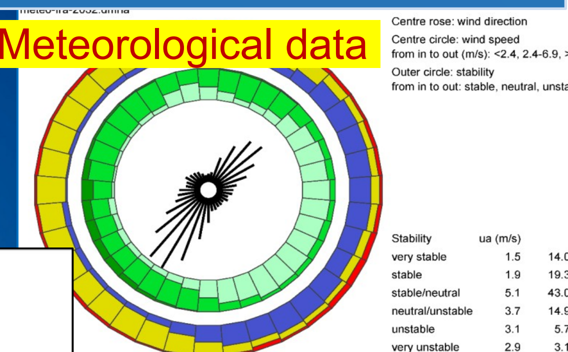
2023 Year

Airport Infrastructure



- CAEPport (MDG database)
- Polish regional airport;

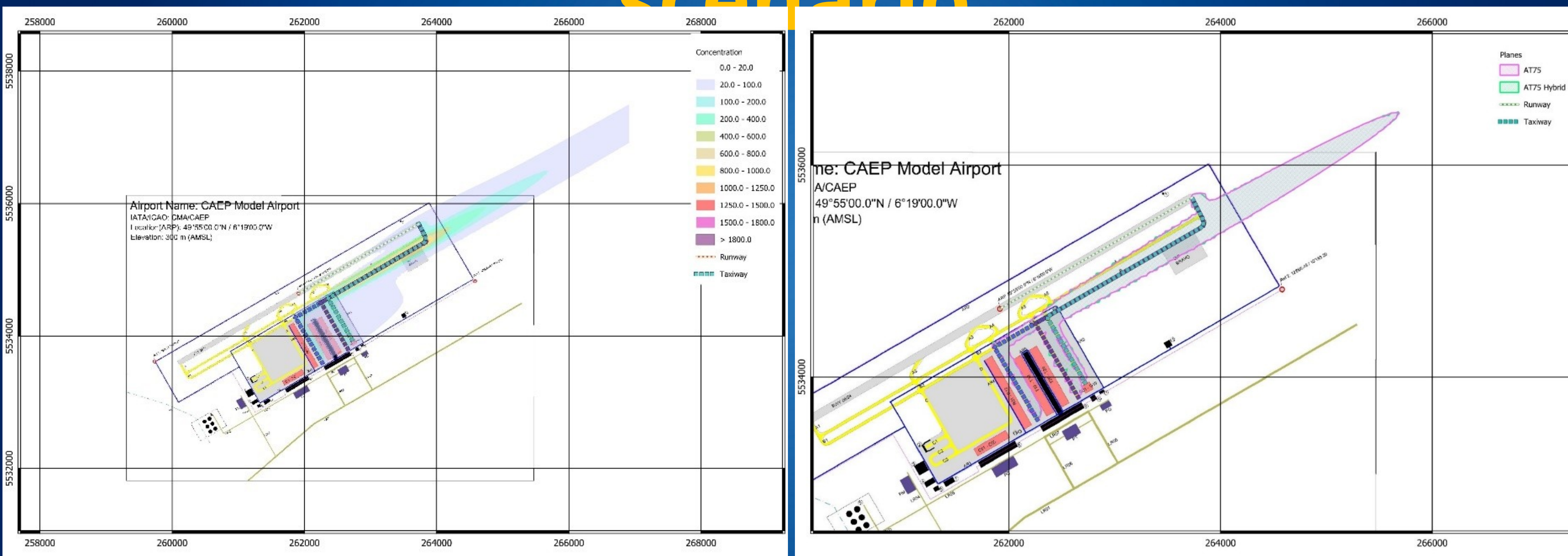
Meteorological data



Dispersion Analysis

- ✓ Calculation of **hour** and **annual mean concentration** of NOx, nvPM;
- ✓ Contribution of aircraft category to hour and annual mean concentration;
- ✓ Determination of the **area** the near-ground concentration exceeds a given **threshold (annual) value, Ab**

Area of LAQ influence: airport scenario



Hourly concentration of NOx [µg/m3] for peak hour (25 operations, including 5 of AT76/A76 hybrid)

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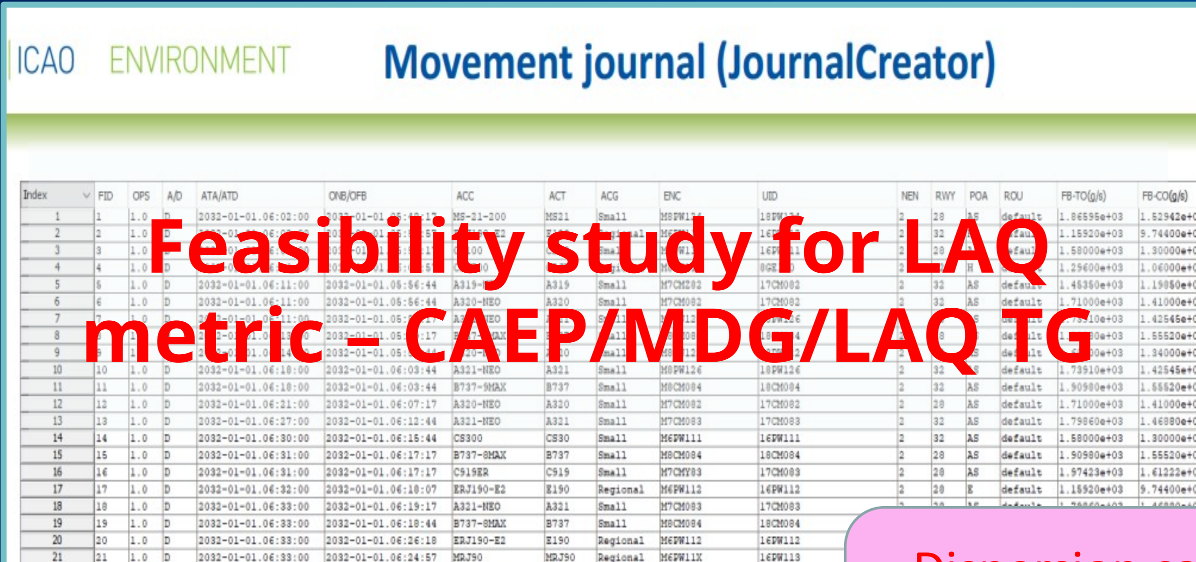
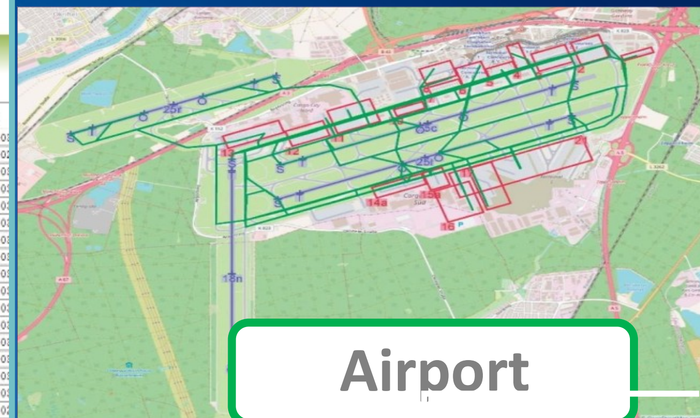
Feasibility study for LAQ metric – CAEP/MDG/LAQ TG

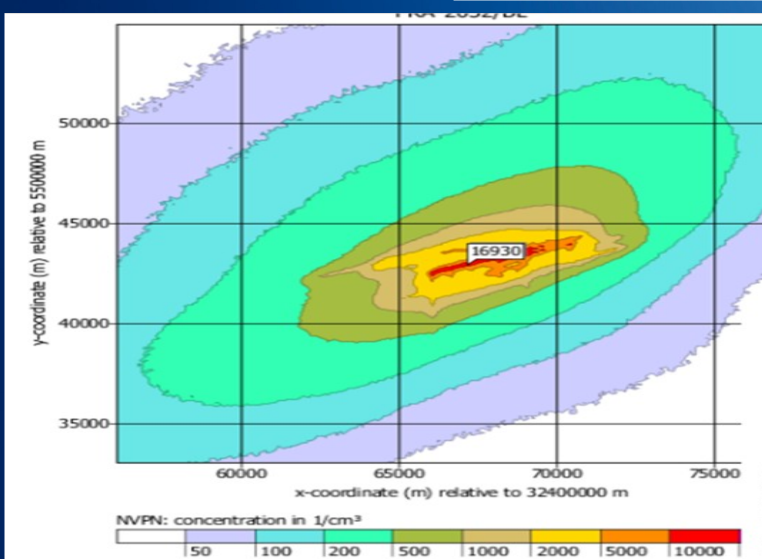




Airport

Dispersion calculation annual mean concentration

Meteorology



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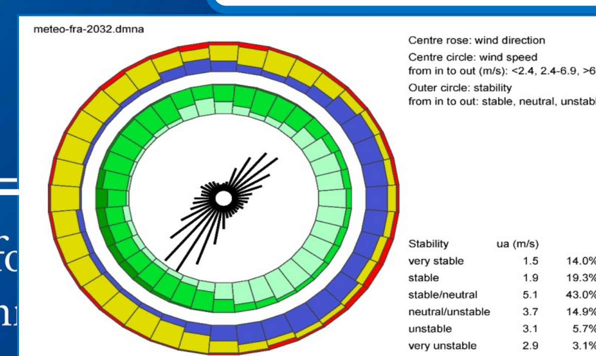

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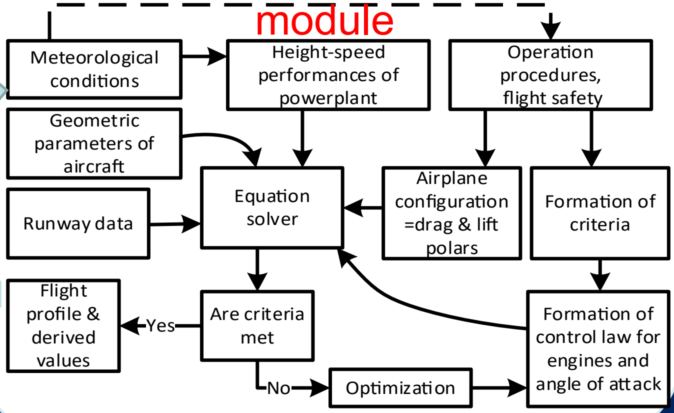
NOISE ACH

Modular approach to evaluation of noise metrics

Aircraft flight profile calculation module



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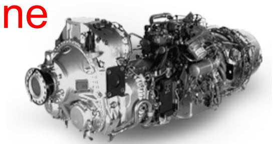

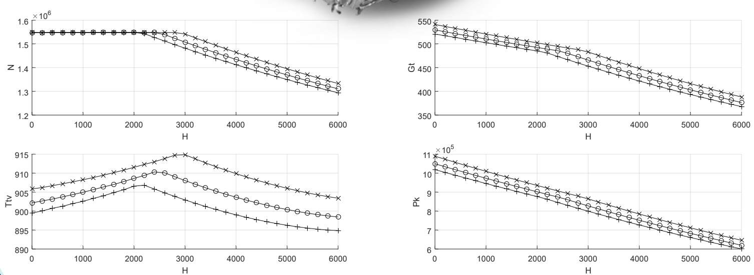

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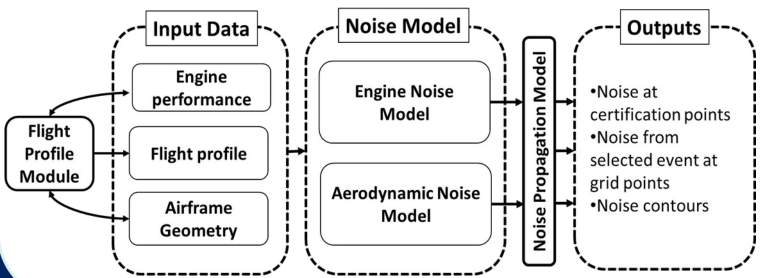

Noise prediction options: spectral, temporal, area domains

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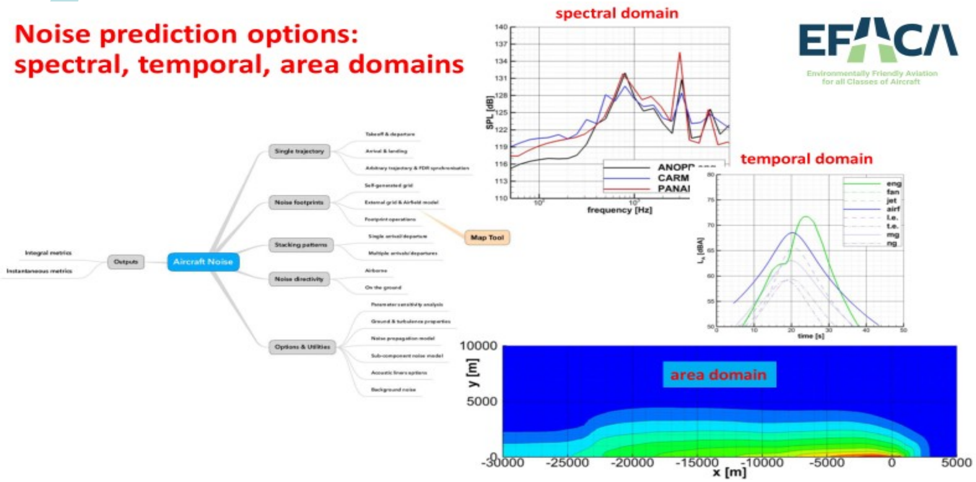

Noise monitoring at Gdańsk Katowice Lublin airports

time history signal processing

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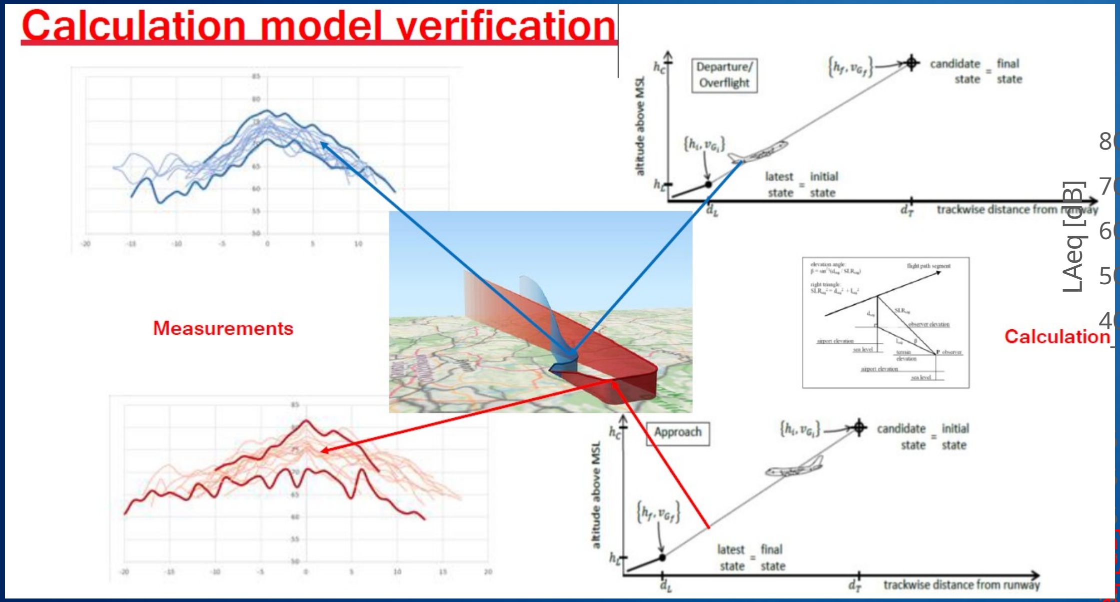

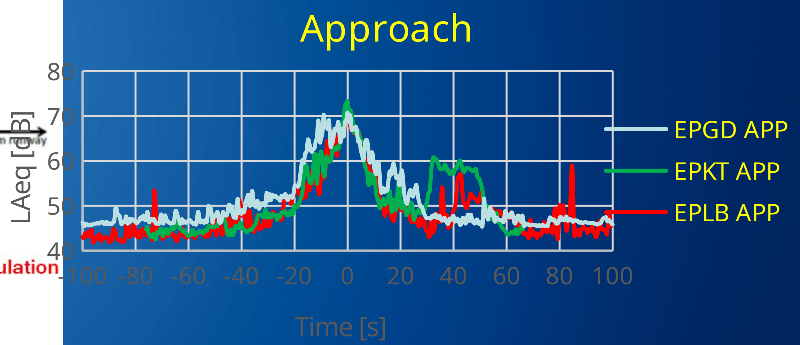

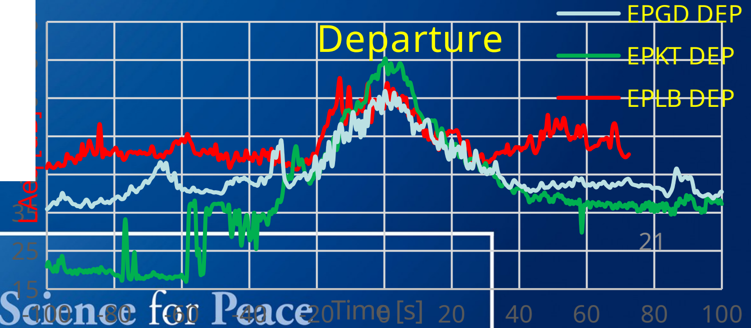

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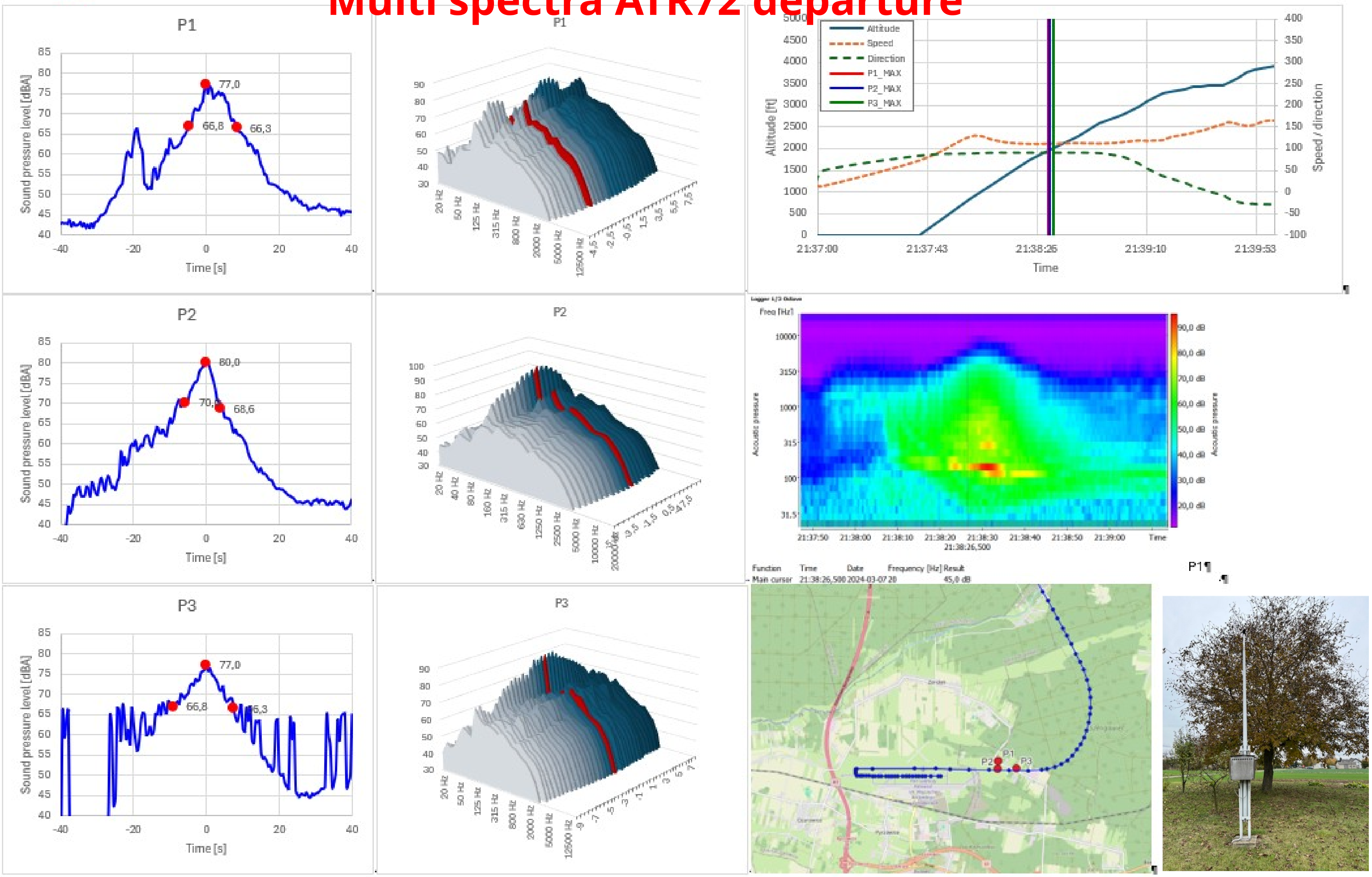
07-03-24 dep RWY08 21-38 SP-PI¶

Multi spectra ATR72 departure



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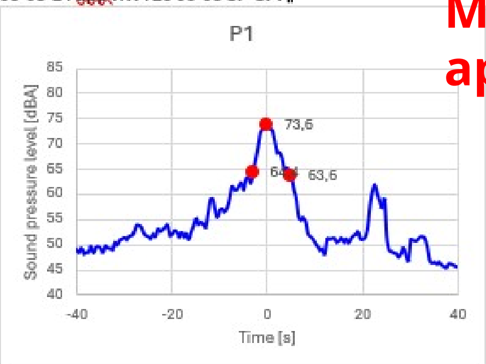
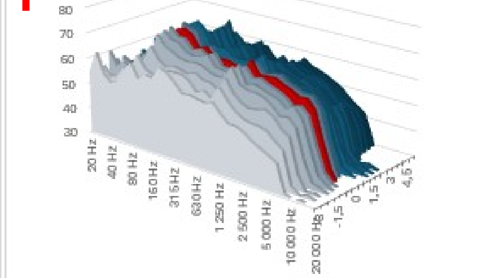
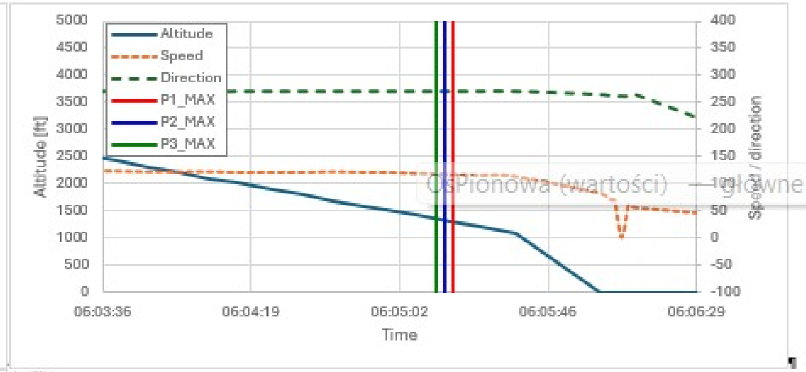
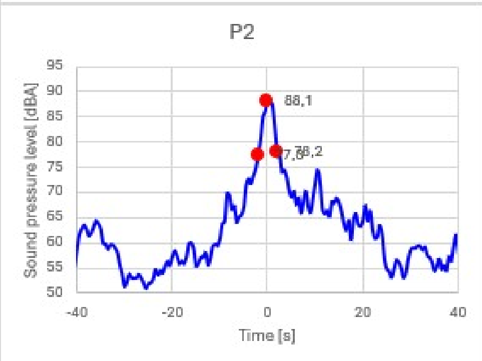
Multi spectra ATR72 approach

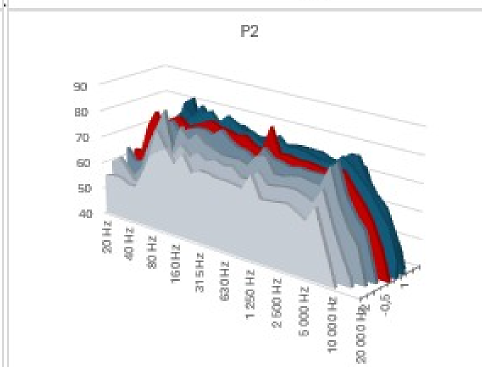
05-03-24 app RWY26 06-06 SP-SPI

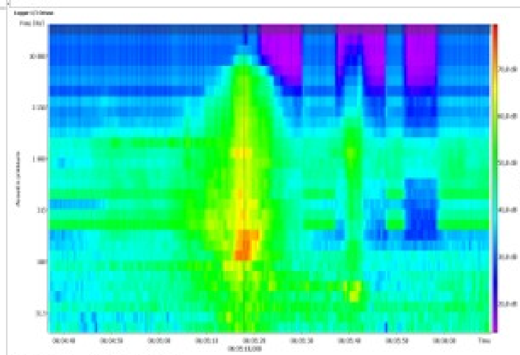


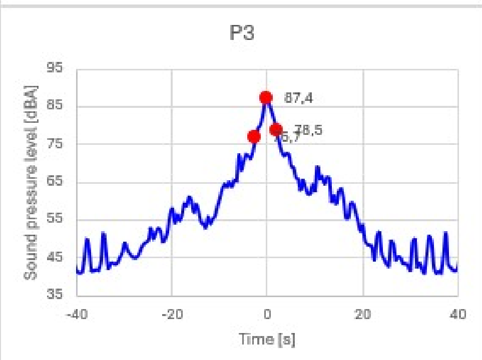


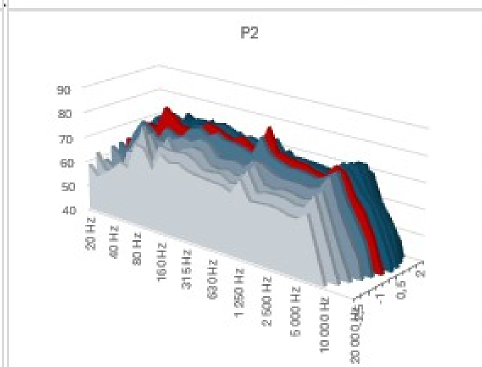












P1

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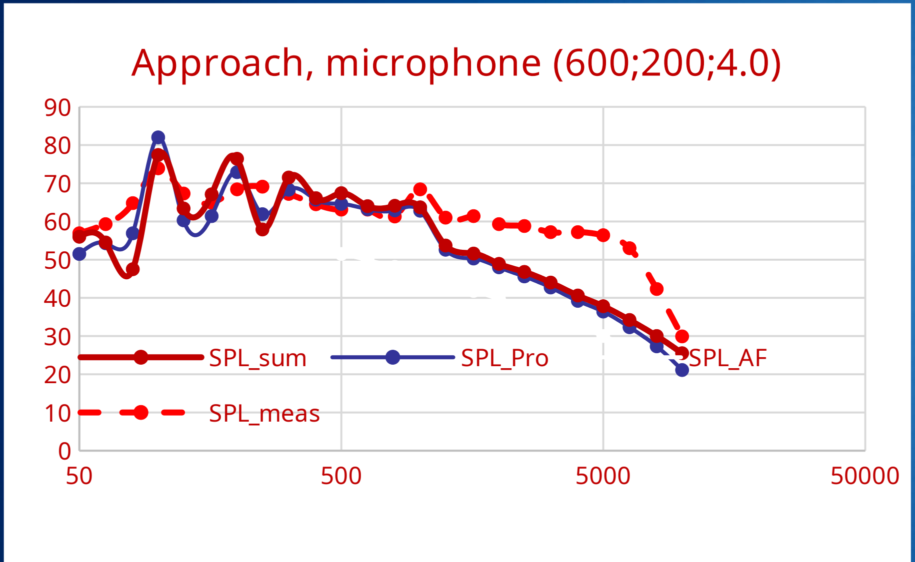
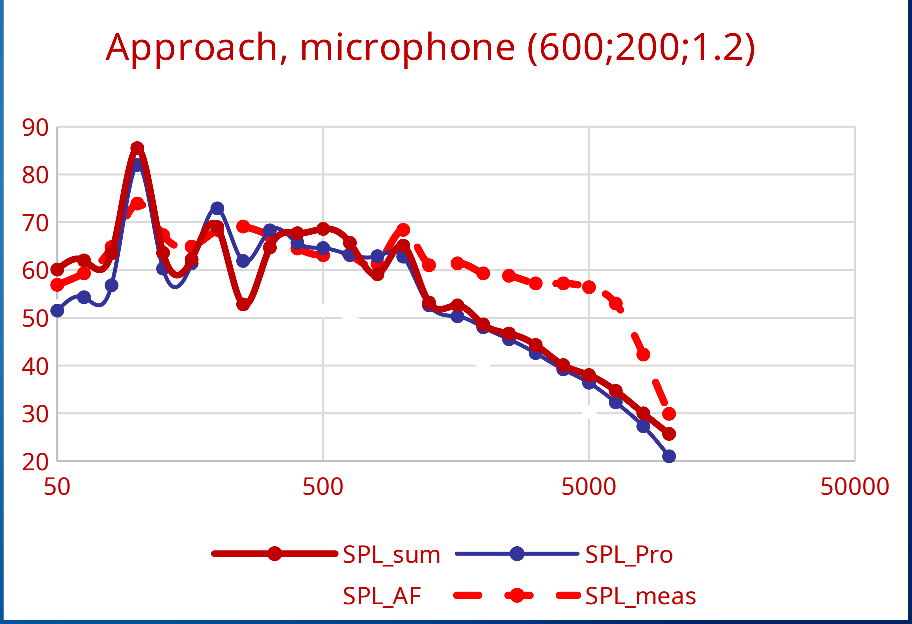
Noise spectrum modelling at monitoring site

Katowice airport, ATR-500

Łukasiewicz Instytut Lotnictwa

NOISE ACH





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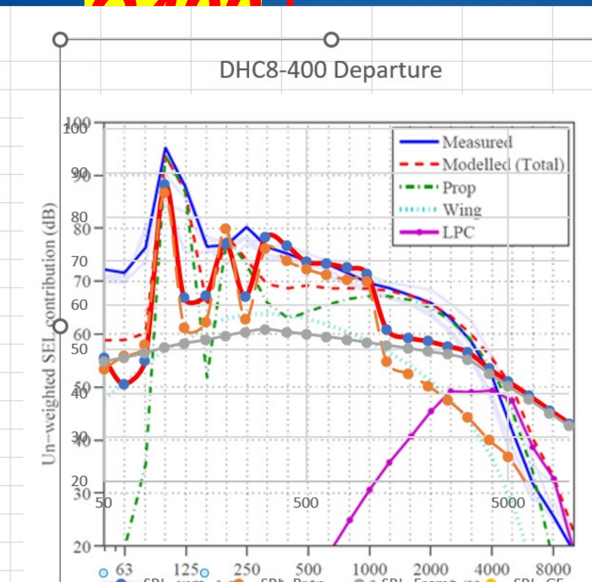
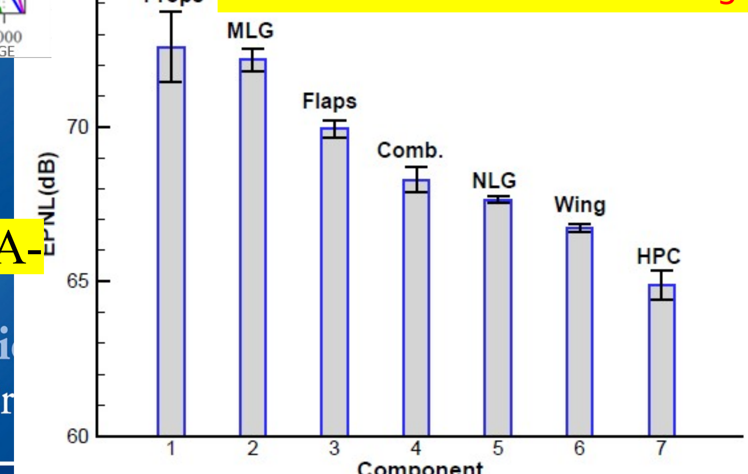
Comparison between the measured and predicted 1/3rd octave band spectra ***Dash8-Q400*** (… e, 2015)

	Frequency,Hz	SPL_sum	SPL_Prop	SPL_Frame	SPL_GE
2	50	48	45,5	47,2	-1,4
3	63	42	48,5	48,1	-9,3
4	80	47,3	51,1	49,1	-5,9
5	100	87,4	85,6	50,4	1,9
6	125	61,7	54,9	51,3	5,2
7	160	62,2	56,2	52,1	4,6
8	200	74	77,4	53	-3,4
9	250	62	56,9	53,9	3,4
10	315	75,4	72,8	54,5	2,6
11	400	73,6	70	53,9	3,5
12	500	69,9	68,2	53,4	1,5
13	630	69,5	66,8	52,8	2,5
14	800	68,5	65,8	52,2	2,5
15	1000	67,2	65,4	51,5	1,6
16	1250	54,5	47,1	50,9	2
17	1600	52,6	44,5	50,2	1,4
18	2000	51,8	41,7	49,5	1,6
19	2500	50,7	38,5	48,8	1,5
20	3150	49,3	34,5	47,7	1,4



Noise contributions at landing



AIR 1407: Prediction Procedure for Near-Field and Far-Field Propeller Noise

Fink, Martin R.: Airframe Noise Prediction Method. FAA-RD-77-29, Mar. 1977

Scenario & Fleet Forecasting: methodology

Operational Level | Global Level

Aircraft vehicle & event scenario model

- *+ Basic aircraft type (ATR72/A320/A220 etc)*
- *+ Novel EFACA aircraft (Propeller Hybrid, liquid hydrogen, cells etc)*

Modelled Event Profile (ISA, etc)

Meteorology & real operation conditions (ADS-B tracking), noise & emission monitoring, comparison with measured data

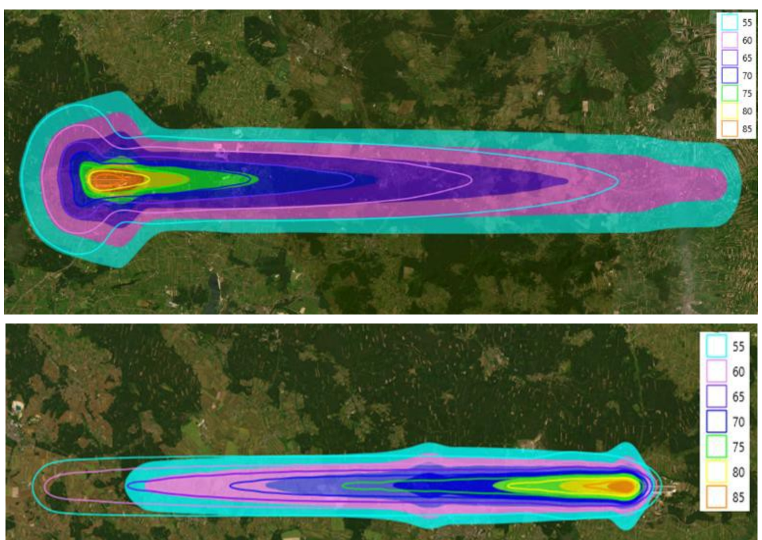


TABLE 2. NOISE LEVELS AT CERTIFICATION POINTS

Source of input data and model applied	EPNL [EPNLdB] at certification points		
	App-roach	Late-ral	Fly-over
EASA Certification Data ATR72-212A for PW127F	92.1-92.5	82.5-82.6	76.3-81.2
INM 6.0 (ANP data)	92.2	96	82.2
INM 7.0 (ANP data)	92.2	90.8	83.1
AEDT 3e, ANP (ASIF): ATR-72-500 PW127F (#1671): Departure Standard 1/Approach Standard	93.2	90.1	80.8
AEDT 3e, ANP (ASIF): ATR-72-500 PW127F (#1671) Departure Standard 3/ Approach Standard	93.2	89.9	83.1
AEDT 3e, ATR 72-500, blue profile (Fig.2)	**88.3-96.1**	**80.5**	**77.8**

Operation case for CAEP airport: data + turboprops

Operational Level | **Airport Level** | Global Level

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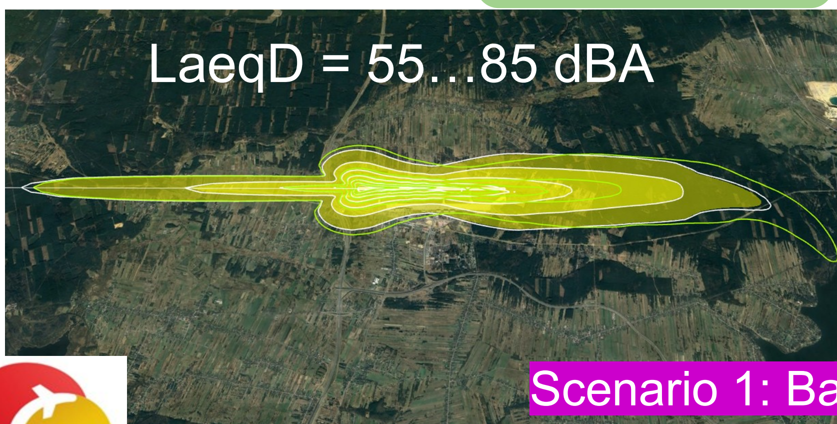

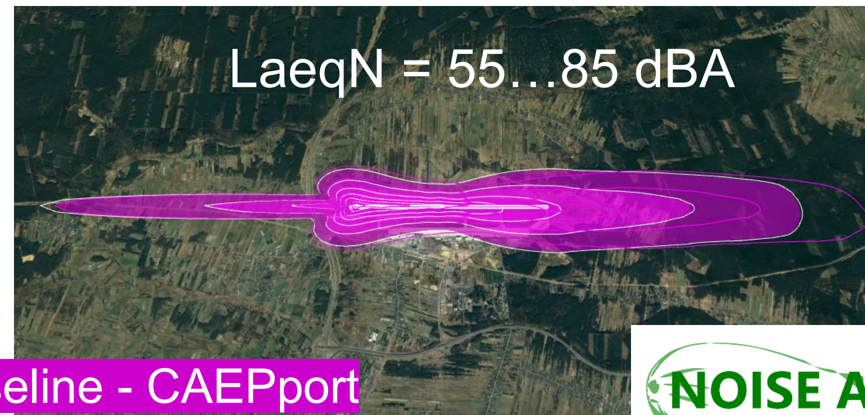

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Scenario 1: Baseline - CAEPport

Scenario 2: Baseline – CAEP port+double ATR72

Scenario 3: Baseline - Max Dep Profiles

Table 1: Flight operations distribution over aircraft groups

Aircraft group	Departures	Arrivals	Operations	Percentage, %
Large	3179	3177	6356	7.2
Medium	713	712	1425	1.6
Small	24109	24604	48713	55.1
Regional	5536	5571	11107	12.6
Business	103	113	216	0.2
Turboprop	9891	10102	19993	22.6
Piston	290	290	580	0.7
Total	43821	44569	88390	100

		Average (Scenario 1)		Scenario 2		Scenario 3 (Max Profile)	
Aircraft group	Rep Type	DAY	NIGHT	DAY	NIGHT	DAY	NIGHT
Large	B777	7	1	7	1	7	1
Medium	A332	0	0	0	0	0	0
	A321	50	16	50	16	50	16
Regional	E190E2	10	5	10	5	10	5
Business	-	0	0	0	0	0	0
Turboprop	ATR72	20	7	40	14	20	7
Piston	-	0	0	0	0	0	0
Total		87	29	107	36	87	29

Variety of methods to reduce noise

Noise — Metric

- **Propulsion** — Domain
  - **Propeller**
    - Variable pitch
    - Optimal number, shape, distribution of the blades
    - Bio-mimetic propeller design
    - Leading and trailing edge serrations
    - Pylon blowing
  - **Jet**
    - Ultra high bypass ratio engines
    - Micro jet devices
    - Chevrons
    - Fan flow deflector
    - Lobed mixers
    - Translating plug
    - Zigzag vortex generator nozzle
    - Wavy inner wall treatment
  - **Engine**
    - Porous materials on OGV
    - 3D-optimized blade design
    - Refining the shape, spacing, and number of blades
    - Active stators
    - OGV-integrated actuators
    - 3D printing of gas-turbines
    - Reduction in fan pressure ratio
    - Reduction in fan tip speed
    - Increase in size of fan
    - Water-enhanced turbofan
    - Liners
  - **Novel configurations**
    - Blended-wing body
    - Full-electric propulsion
    - Distributed electric propulsion
- **Airframe**
  - **Wing**
    - Vortex generators
    - Engine shielding
    - Brush at the trailing edge
    - Droop nose at the leading edge
  - **Landing Gear**
    - Fairings
    - Rims on wheels
    - Caps on cavities
  - **High-lift devices (HLD)**
    - HLD edges made of porous materials
    - Slat gap optimization or suppression
    - Slat chevrons
    - Fractal spoilers
    - Continuous Mold-Line Link flap

Technologies
*Sampling -not inclusive list

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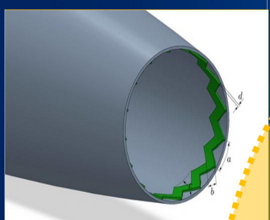
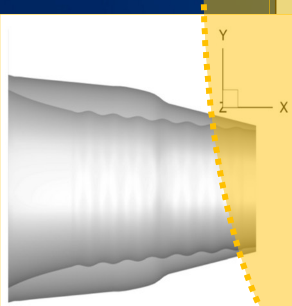
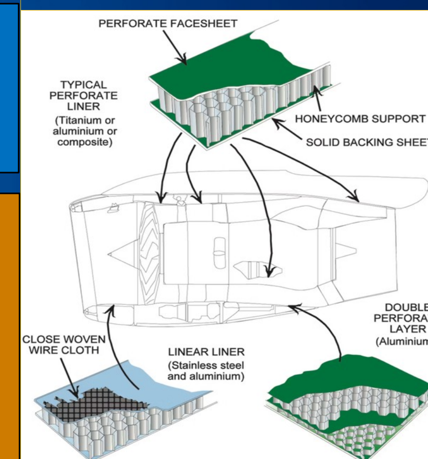
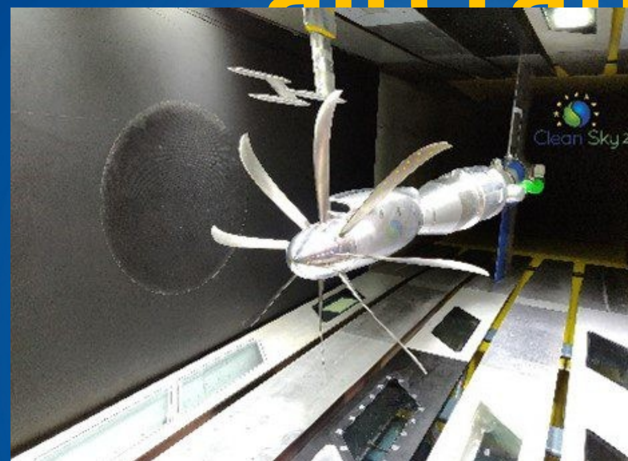


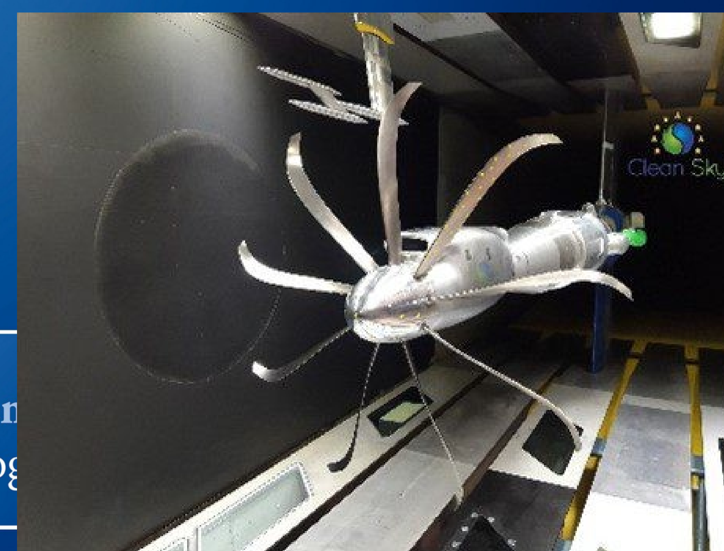




IRON Turboprop aircraft



The IRON project (under Europe's Clean Sky 2) has focused on the design and testing of new, innovative propellers, setting the ambitious target of a **6 dB near-field noise reduction** at cruise compared to a baseline design



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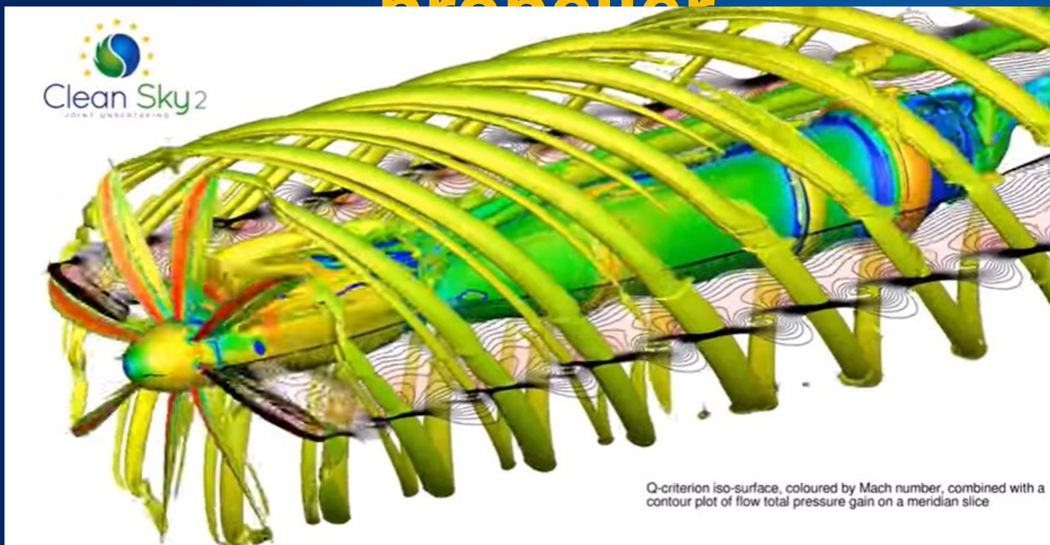
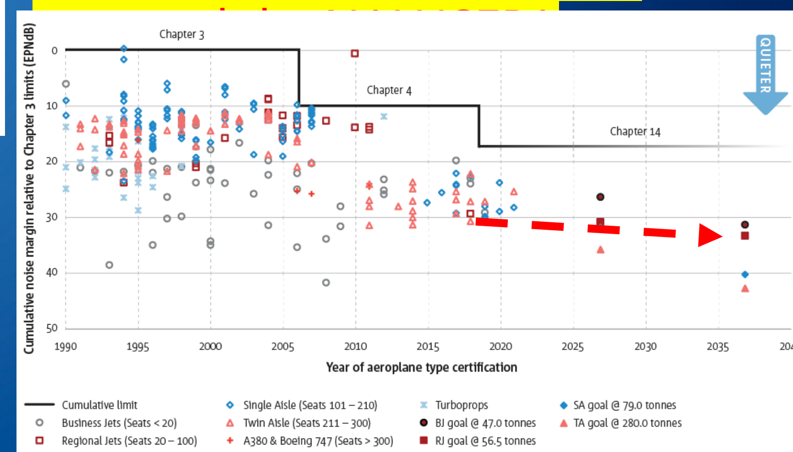
Low-noise designs for propeller



The baseline propeller design was developed by Dowty Propellers and/or Hamilton Standard

Innovative low-noise propeller designs will be assessed via CAA codes by Ilot and analytical



- *Innovative low-noise designs* will be needed to reach Europe's ambitious long-term targets and propeller technologies must keep advancing to fulfil the needs of the industry

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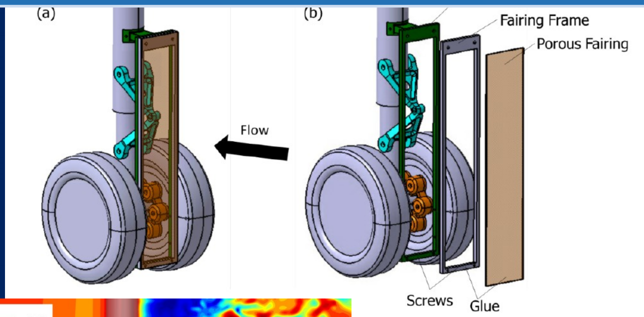
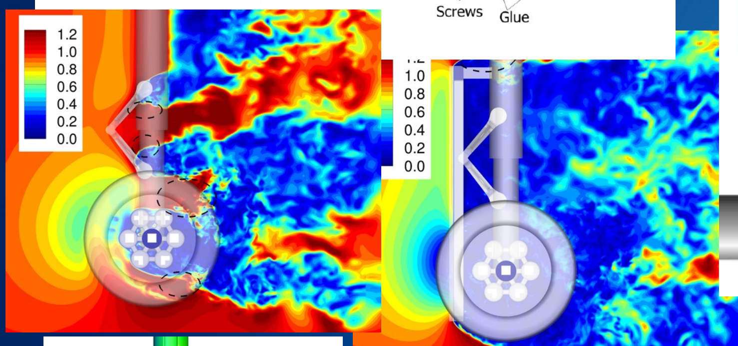
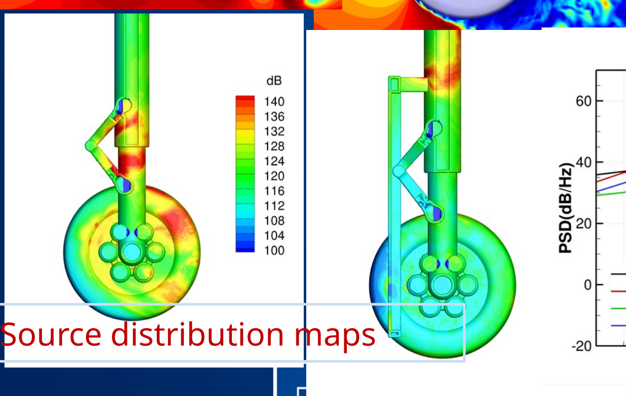
“Capacity Building for a New Generation of Scientists in Energy Security and Climate Neutrality”
Advanced Study Institute. Budapest, October 8-16, 2024

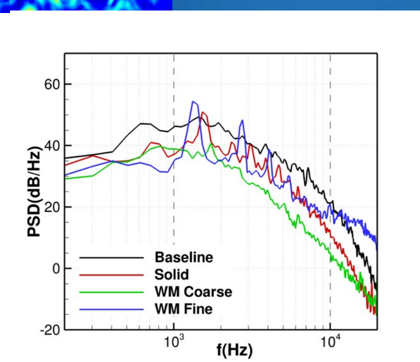
EU INVENTOR project



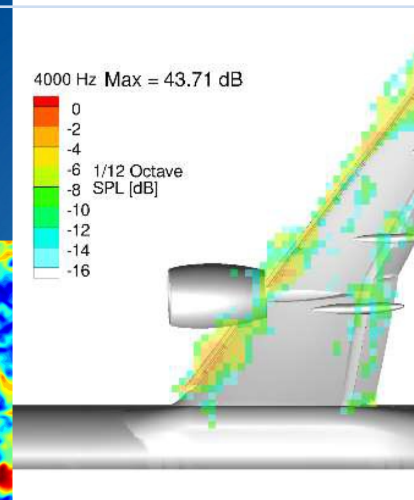


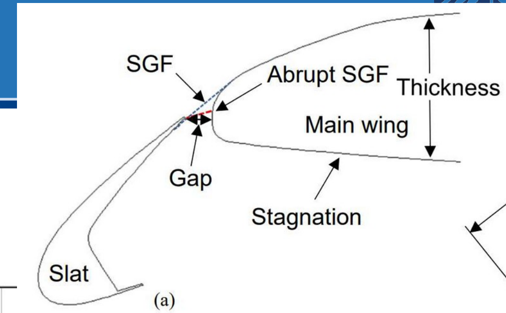


Source distribution maps



Source distribution maps





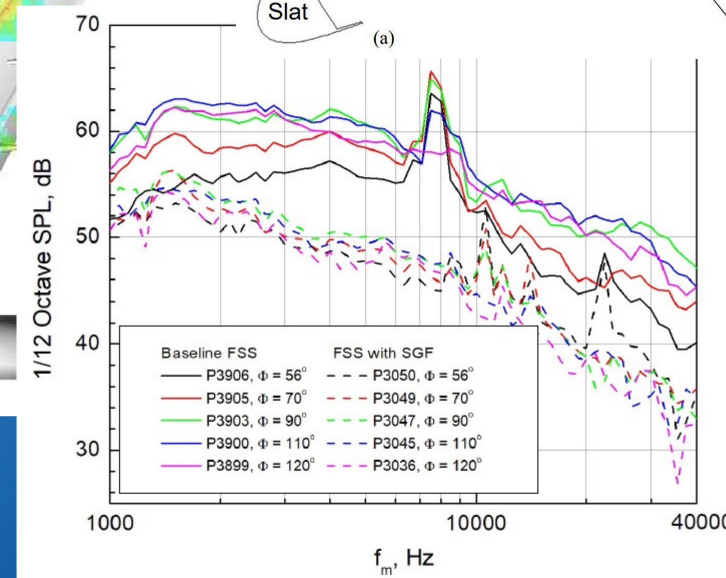
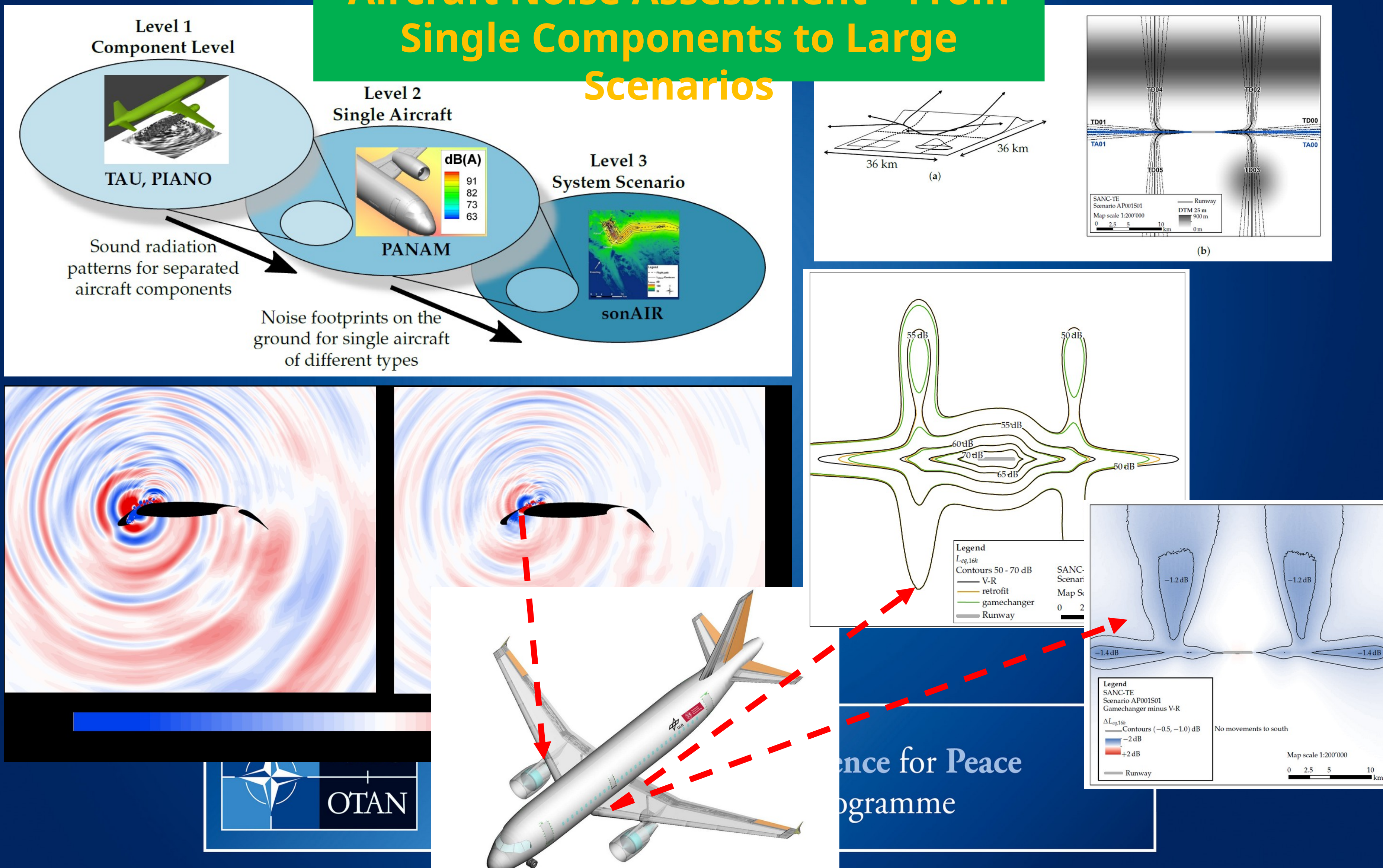


Fig. 34 Comparison of Configurations 1 and 3 (Baseline FSS and FSS with SGF) α = 8.5°, M = 0.16.

Mounting support (green), fairing frame (grey) and porous fairings (orange, translucid): **noise mitigation levels 5-10 dB!**

The Slat-Gap Filler (SGF) employs an overleaf concept and sustains the local aerodynamic loading when Full-Span Slat (FSS) deployed: **around 10 dB noise reduction at f>1000 Hz**

Aircraft Noise Assessment—From Single Components to Large Scenarios



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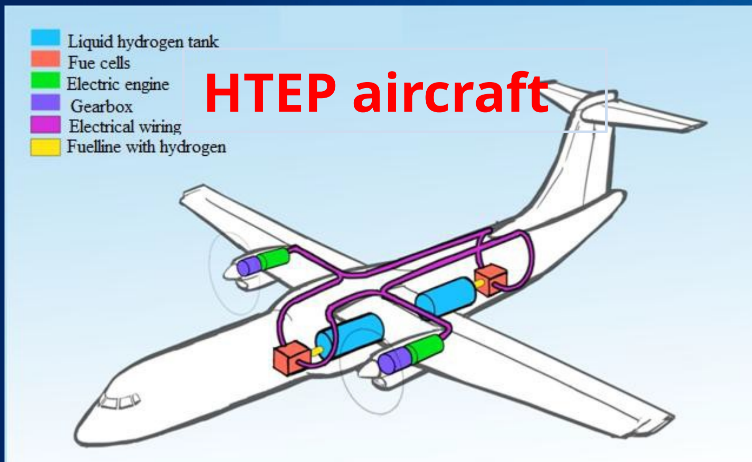
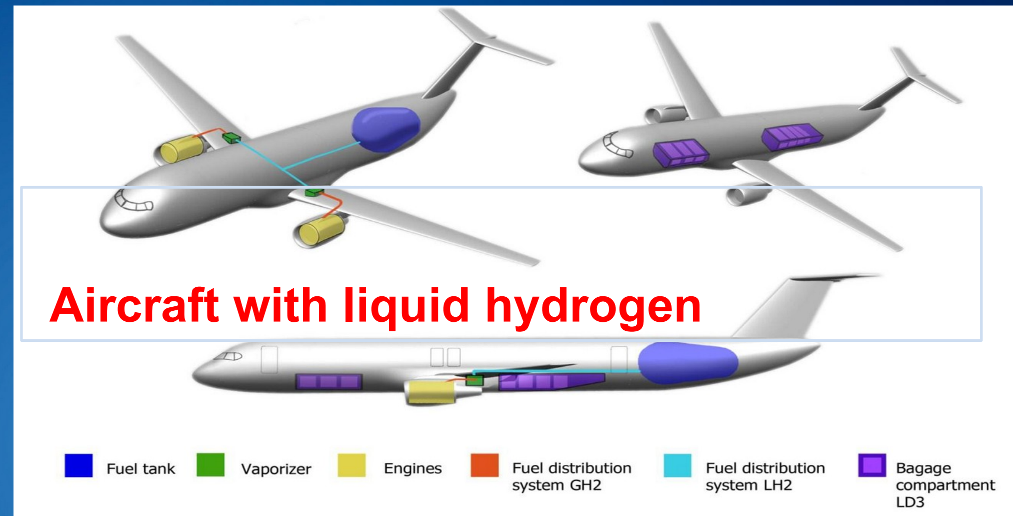
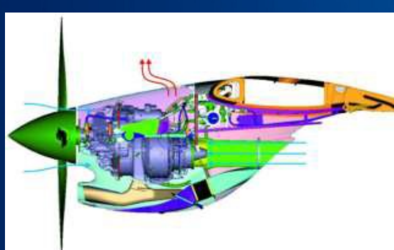
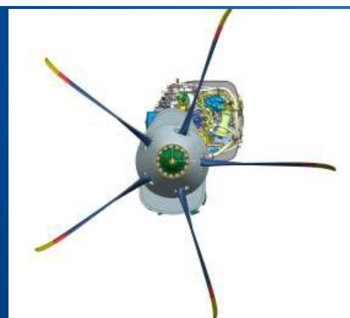
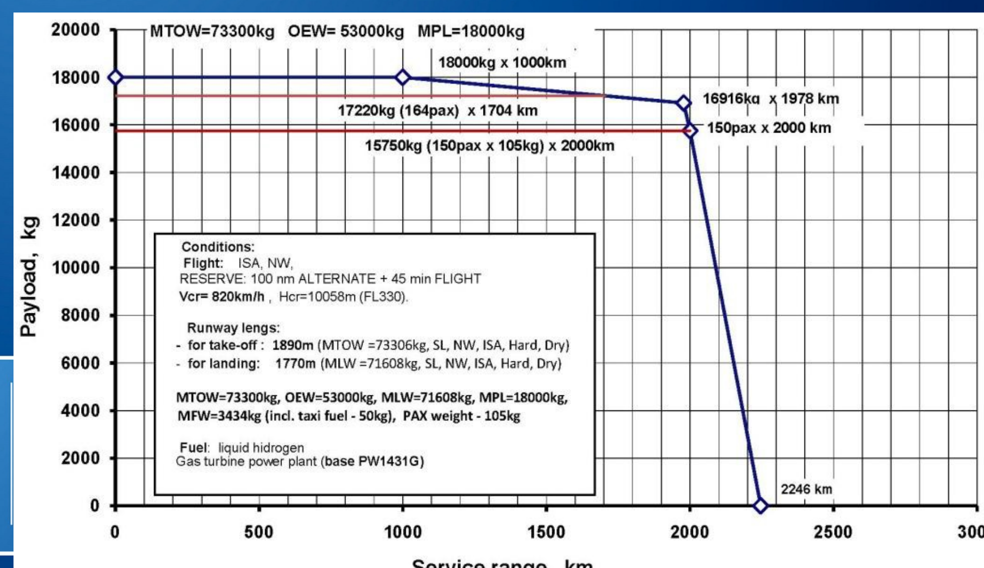
EFACA aircraft design platforms











New aircraft!

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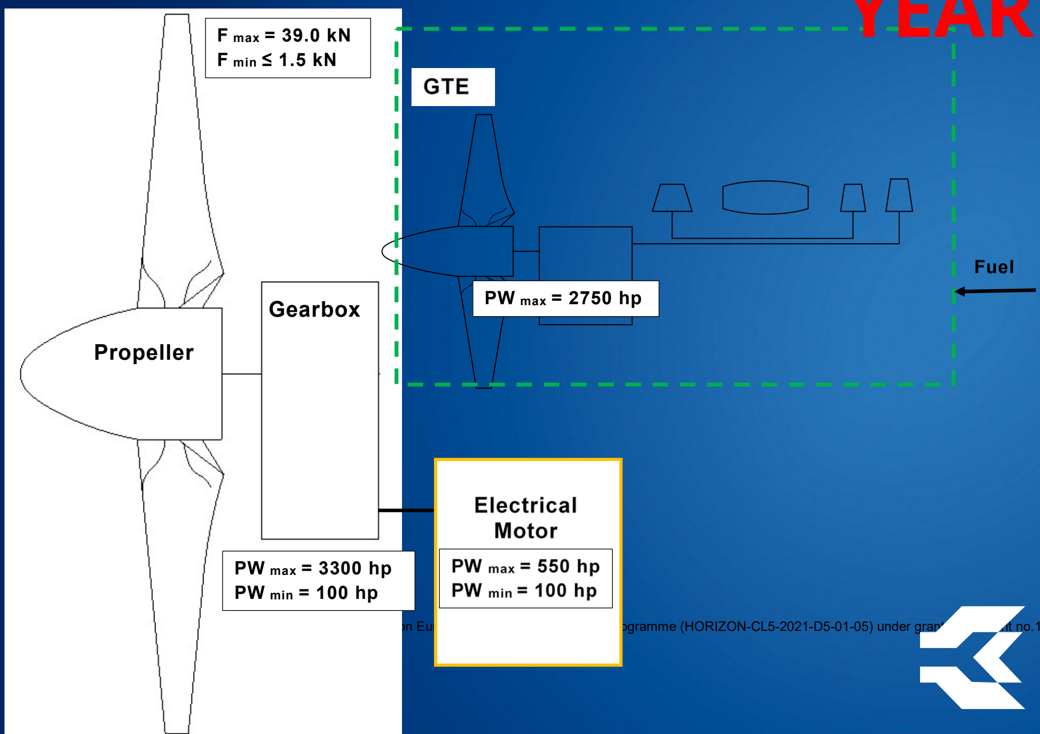
KEY RESULTS FOR FIRST YEAR



- The level of hybridization of the propulsion system, i.e. its influence on the dimensions and mass of the HTEPs, and therefore on the RA configuration.
- The electrical power management strategy for the co-design of the RA components and the HTEP.

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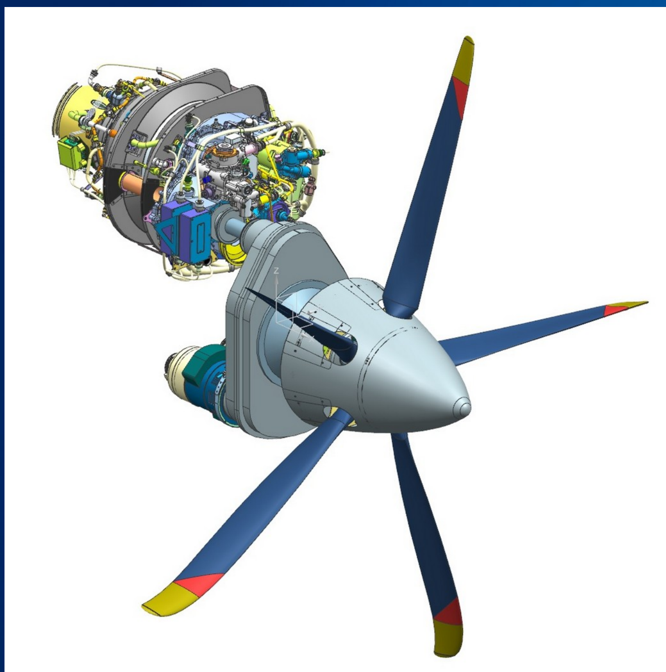
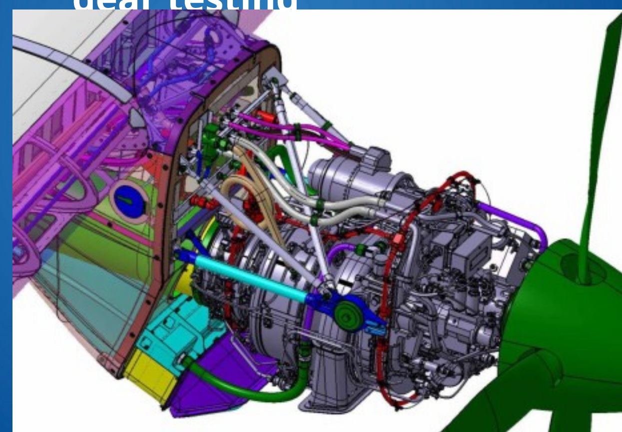
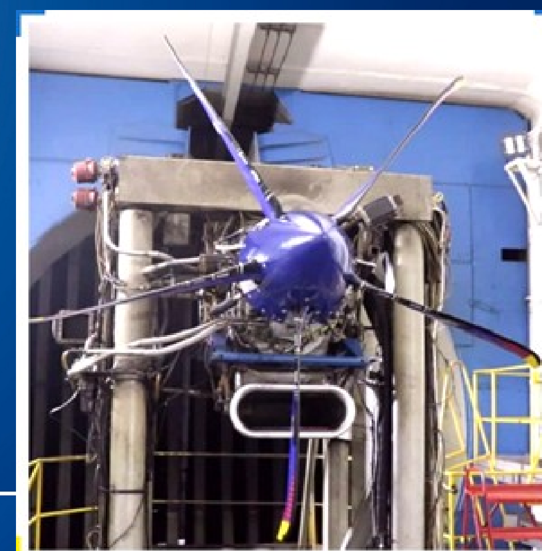
For HTEP demonstrator must be developed by 2026



- mounting frame adopted for EM and demonstrator reduction gear
- test rig adopted for GTE, EM and demonstrator reduction gear testing





IVCHENKO PROGRESS

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ACARE / Clean Aviation goals achieving climate neutral air mobility in 2050

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Aviation in the european energy and fuels system

Accelerate the progress towards the ACARE SRIA goals for 2020-2050

Short-term (<2030)

- Aviation is fully integrated with the European energy and fuels sector to ensure availability, affordability and security of supply;
- By 2030, SAFs make up 10% of all of the aviation fuel consumed in Europe for intra-EU and departing flights;
- By 2030, sustainably produced hydrogen will be available in key EU airports for ground operations and aircraft demonstration;

Medium-term (<2035)

- In Europe, by 2035, 20% of conventional jet fuel is replaced by sustainable aviation fuel.

Long-term (<2050)

- By 2050, over 80% of conventional fuel will be replaced by SAF;
- By 2050, sustainable hydrogen is available as an aviation fuel at all European airports;
- The energy and transport chains are integrated within the mobility as a service system, e.g. the passenger can ride on a hydrogen powered bus to an hydrogen powered airport to board an hydrogen powered flight.

By 2030, net CO_2 emissions from all intra-EU flights and those departing the EU are reduced by 55% compared to the 1990 baseline

By 2035 new technologies, fuels and operational procedures in service result in a 30% reduction in non-CO_2 climate effects of all intra-EU flights and those departing the EU relative to the 1990 baseline

- **By 2050** technologies, operational improvements and noise abatement procedures **reduce the perceived noise** emission of flying aircraft **by 65%** per operation relative to the 2000 baseline;

“Capacity Building for a New Generation of Scientists in Energy Security and Climate Neutrality”

Advanced Study Institute. Budapest, October 8-16, 2024

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ILot, NOISE & CEPA with EFACA coordination for NATO Security

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