Systems for Green Operations
Clean Sky Final Event
Why Systems developments in Clean Sky?

- Direct contributions to environmental objectives
- Smart answers to market demands
  - Increased Equipment performance for extended A/C needs
- Enablers for A/C innovations
- Enablers for Air Transport System optimisation
Systems for Green Operations - concepts

- Pillar 1: Management of Aircraft Energy (MAE)
  - The use of all-electric equipment system architectures will allow a more fuel-efficient use of secondary power, from electrical generation and distribution to electrical aircraft systems.
  - Thermal management will address many levels, particularly relating to electric aircraft, from hot spots in large power electronics to motor drive system cooling, to overall aircraft solutions.

- Pillar 2: Management of Trajectory and Mission (MTM)
  - The agile aircraft will generate a reduced noise footprint during approach by flying optimised trajectories.
  - Aircraft will be able to fly a green mission from start to finish, thanks to technologies which allow to avoid fuel consuming meteorological hazards and to adapt flight path to known local conditions.
SGO Consortium setup - Leaders

- Definition of the technical roadmap for the 7 year program
- Steering of the main activities towards demonstrators
- Development of critical system building blocks
- Integration into test rigs

Leaders

Funding: 75M€
18 Individual beneficiaries
SGO Consortium setup - Associates

- Selected in 2007-2008 to provide major sub-systems for integration into demonstrators
- Contributed to the technical roadmap for the 7 year program

**Leaders**
- Funding: 76 M€
- 18 Individual beneficiaries

**Associates**
- Funding: 33 M€
- 15 Individual beneficiaries
SGO Consortium setup - Partners

- Selected in 16 open calls from 2009 to 2015
- Specific objectives completing the roadmap

**Leaders**
- Funding: 76 M€
- 18 Individual beneficiaries
- 107 Projects

**Associates**
- Funding: 33 M€
- 15 Individual beneficiaries

**Partners**
- Funding: 37 M€
- 150 Individual beneficiaries
- Selected in 16 open calls from 2009 to 2015

... and many others

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Scope – SGO for Large Aircraft

- WP2.3.6 VCS
- Electrical ECS
- Skin HX
- Electrical WIPS
- Engine Nacelle Sys
- Electrical Power Center
- Wiring System
- Generators and Converters
- Electrical Taxi
- Weather Avoidance
- Flight Management
- Ice Detection
- Fuel Cells
- Fuel Cells and Converters
- Electro-thermal
- Hybrid

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Scope - SGO for Green Regional Aircraft

- Electrical WIPS
- Electrical ECS
- Generation system and Rectifiers
- Flight Management
- Electrical Architecture Optimization Tool

CLEANSKY - Systems for Green Operations Proprietary and Confidential
Scope – SGO for Green Rotorcraft

HEMAS

Generator and Converter

Electrical Tail Rotor Drive

AIRBUS

LEONARDO
Scope – SGO for Eco-Design

- Converters and Rectifiers
- Switching Components
- Electrical WIPS
- Generator and Converter
Clean Sky Mission and Trajectory management
Main demonstrators

- Optimized departure Procedure – Pilot in the loop ground tests
- Advanced Weather Radar & EFB Crew Decision support tool on Regional A/C Simulator
- Smart Operation on Ground – Full scale dynamometer tests
- Time and Energy Managed Operations Flight Tests
- FMS functions: Final test on System test bench

2014-Q2
- Optimized departure Procedure – Pilot in the loop ground tests

2015-Q2
- Advanced Weather Radar & EFB Crew Decision support tool on Regional A/C Simulator

2015-Q4
- Smart Operation on Ground – Full scale dynamometer tests

2015-Q4
- Time and Energy Managed Operations Flight Tests

2016-Q3
- FMS functions: Final test on System test bench
FMS Green functions: Objectives

- Multi Criteria Departure Procedure
- Optimised multi step
- Time & Energy Managed Operations
- Increased Glideslope

Specific functions for each phase, exploiting the degrees of freedom available for optimisation
Adaptive Increased Glideslope

Provides the flight crew with optimised final approach procedure
- Without requiring additional approach publication
- Without requiring additional infrastructure means
- Only when conditions allow it
- Maintain the same level for safe and operational practices

Validated at TRL5 in Airbus Mosart Simulator
Demonstration of Trajectory optimisation function in Ground simulator:

- **Multi-criteria departure procedure**: optimisation according to mission condition  Q3-2016
- **Multi-Step Cruise**: real-time computation of optimal flight levels  Q4-2016
- **Adaptive-Increased Glideslope**: slope according to mission constraints  Q2-2016

**Representative test environment**

**Pilot-in-the-loop validations**
Focus: Crew Decision Support tool

- Use of polarimetry to evade identified hazardous area
- Validation in cockpit / ATC simulator
- Support of Several CfP Partners (Antenna feasibility, EFB implementation, in flight data gathering, ...)

Re-planned Trajectory
Focus : Electrical Wheel Actuation

- An innovative system allowing aircraft to pushback and taxi without main engines running
- Energy recycling functions studied via a CfP Partner project
- Full integrated SOG system validation on A/C representative dynamometer test rig
- TRL4 at system level validated, TRL5 requires additional motor integration in the wheel, continued in Clean Sky 2
Systems for Green Operations (SGO) - Break Out Session
GSAF & TEMO by Wilfred Rouwhorst (NLR)

Clean Sky 1 – Closing Event
Brussels, March 21\textsuperscript{th} - 22\textsuperscript{nd}, 2017
GSAF: Green Systems for Aircraft Foundation

GSAF: an International Cluster, consisting of:
- Netherlands Aerospace Center (NLR) – Cluster Lead
- Aeronamic B.V., a Dutch SME (AER)
- Delft University of Technology (DUT)
- Cranfield University (CU)
- University of Malta (UOM)

an Associate Member in Clean Sky 1 (SGO & TE)

was Associates Representative in Governing Board (GB)

Very successful collaboration and contribution to CS1
GSAF partly active inside TE (NLR, CU) and strongly inside SGO for:

MAE - GSAF (AER, NLR, TUD)
Developed advanced Starter-Generator

MTM - GSAF (CU, NLR, TUD, UOM)
Developed “Greener Aircraft Trajectories under ATM Constraints” - GATAC

Developed TEMO, partly with DLR & CfP partners
Set out 3 Call for Proposal (CfP) topics
Time and Energy Managed Operations (TEMO)

SGO  CS1 Final Event
Brussels, March 21-22
OSAKA Itami Airport: huge quality of life issues...
Address Environmental & Capacity Issues

One Solution:
Build a new airport in Sea, like done for OSAKA Kansai KIX Airport

Not always an option for other: (EHAM, EGLL)
- CDOs provide noise, fuel and emission benefits
- Challenge: develop a concept that maintains operational benefits of an idle descent, while maintaining airport capacity at peak work hours
So, why TEMO?

- Current CDAs (CDOs) **suffer from loss of runway capacity** due to increased aircraft separation by ATC
- TEMO addresses this aspect
- Addresses SESAR Operational Improvement (OI) TS-103: Controlled Time of Arrival (CTA) through use of datalink
- Part of 4D trajectory management
- Connects to SESAR 1 - STEP 2 capabilities
TEM0 Concept – Main Aspects

- Time constraints at IAF or RWY
- Non Linear Programming (NLP) solver
- Optimize for noise, emissions and/or fuel consumption
- Considers Weather Forecast
- Procedural/Operational constraints are respected
- Results in: Optimized Speed + Thrust / Speed-Brake plan
- Fly Speed-on-Elevator

Generate New Optimized plan when:
- Predefined boundaries are exceeded
- ATC imposes new time constraints (on IAF or RWY)

During descent Energy and Time deviations are monitored
Validated from **TRL-3** (batch studies), via **TRL-4** using fixed based simulators up to **TRL5** using full flight simulator

Subsequently the Clean Sky **Flight Trials** tested TEMO beyond TRL-5 towards TRL-6 (meaning **TRL5+**).
TEMOS: 2 Variants Flight Tested

- TUD & NLR: Cessna Citation II – full optimiser and replan capability
  - To demonstrate full TEMO capabilities ↔ business and smaller aircraft market

- DLR: D-ATRA – retrofit and EFB capability, No replan but tactical controller
  - To demonstrate TEMO potential to the air transport market ↔ larger aircraft
TEMO Cessna Citation
Flight Trials
Set up
TEMO - Flight Test Objectives

- Demonstrate ability of the TEMO algorithm
  - to provide accurate, consistent & safe aircraft guidance
  - to meet absolute time requirements at IAF and/or RunWaY threshold
- Obtain pilot feedback on operational & safety aspects
- Collect data to allow TEMO performance evaluation
Test equipment
Fly By Wire System

modified A/P in avionics bay

EC annunciator on instrument panel

FBW controller panel in pedestal
Test equipment  Test Leader Position
6 x 17” cabin racks

- Research FMS computer
- Console display
- Keyboard
- Trackerball
- FTIS computer
- HMI computer
- LOG computer
- FTIS-a/c interfaces
- FTIS-FBW interface
TEMO - Test equipment
Experiment cockpit display

17.1” colour LCD touch screen
TEM0 - Flight crew HMI
P-RNAV ILS Cat I approach for RWY23 at Eelde

Each run started at altitude FL240, speed 230 kt, and about 75 NM DTG.
TEMO Flight Test Movie

A photograph of an aircraft in flight over a landscape.
DLR’s TEMO FT Main Considerations

- No re-generation of flight plan due to 4D-tactical controller
- 4D-Controller integrated into D-ATRA A320 aircraft
- iPad coupled to a/c systems
- Demonstrate a retrofit solution for aircraft with minimum impact on today’s avionics, hence independent use of FMS
DLR’s TEMO FT Cockpit HMI

- Aircraft laterally flown in managed mode
- Guidance information presented on an iPad, used as an EFB
- Speed and Altitude manually selected via FCU based on iPad

Presented On iPad
TEM0 – Main Flight Test Results – both campaigns

- NO Human Factors issues identified with EFB-based operation
- TEM0 assessed by test pilots as SAFE and ACCEPTABLE
- Environmental Gains (Fuel & Emissions) about 10%
- TEM0 replanning observations:
  - Planning aspects
    - Start of replan sometimes too dynamic, requires further tuning
  - Guidance aspects
    - Speed Plan for vertical guidance was followed well (mean error within 1 kt)
    - Achieved Time Accuracy was +/− 2s => better than required +/− 10s
    - Interception at ILS G/S sometimes not properly performed
TEMO - Contribution of 3 CfPs

- **2011 - 2012: NOCONDES** (= Novel Continuous Decent Simulation Test Support) by AVTECH, USE2ACES BV and CERTIFLYER BV
- **2012 - 2014: FASTOP** (=Fast Optimiser for continuous descent approaches) by GTD, UPC and ASCAMM
- **2014 - 2015: CONCORDE** (Flight Operations for Novel Continuous Decent ) by Pildo Labs, University Politechnical de Catalunya

- **FASTOP**: provided new, faster optimiser s/w tool for TEMO inside flight simulators allowing to qualify for TRL5
- **NOCONDES** and **CONCORDE** provided operational support: e.g. pilots, HMI development support, experiment plan creation, piloted validations, experiment-(data-) analysis and reporting, for TRL4-5 and **CONCORDE** also for Flight Test towards TRL5+
Final Remarks

- Clean Sky 1 produced TEMO-innovation for Greening Aviation
- R&D towards higher TRLs, including Flight Testing achieved
- CS1: a Collaboration Program that worked

=> Successful joint work of Research Centers, Academia (Universities) and important involvement of various CfP partners
Clean Sky Management of Aircraft Energy
Main demonstrators

- Icing Wind Tunnel tests of 3 WIPS technologies
- Skin heat exchanger (LSHX) – A320 ATRA Flight Test
- Smart Electrical Power Distribution Center – Ground test
- Electrical Environment Control System Flight tests
- Helicopter Electro-Mechanical Actuation System (HEMAS) Demonstration tests

Timeline:
- 2012-Q4: Icing Wind Tunnel tests of 3 WIPS technologies
- 2014-Q3: Skin heat exchanger (LSHX) – A320 ATRA Flight Test
- 2015-Q2: Smart Electrical Power Distribution Center – Ground test
- 2016-Q2: Electrical Environment Control System Flight tests
- 2016-Q3: Helicopter Electro-Mechanical Actuation System (HEMAS) Demonstration tests
Focus: Flight Test Liquid Skin Heat Exchanger (Q3-2014)

- Skin heat exchanger (LSHX) - FLIGHT TEST in September 2014

Experimental Liquid Loop System (ELLS)

Flight Test Observer Station

Skin Heat Exchanger

Boundary Layer Rakes
Focus: WIPS Icing Wind Tunnel Tests (Q4-2012)

- 3 full scale technology demonstrators at NASA IRT in November 2012
- Test results validated TRL4
Focus: Electrical Ground Tests

- 2 test campaigns running from 2011 to 2013 and 2013 to 2016
- Objectives
  - Functions evaluation & performances
  - HVDC network quality assessment
  - V&V means completion

Electrical Ground Test Rig PROVEN @ Airbus
Focus: eFTD
Achievement summary

- More than 60 technology threads studied
- More than 85 TRL gates passed
- Around 50 Flight Tests hours
- More than 500 publications
- More than 40 patents filed
- More than 40 SMEs involved
- More than 60 Academic partners

AWARDS: Best PhD, Best CfP project
**ITD assessment of Environmental Benefits Single Aisle**

**SGO fuel gains for different mission ranges and Aircraft take-off weight**

- **Fuel Gains between 2% and 8% depending on mission range**
- **Highest fuel gains in shorter missions**
- **Average gain on worldwide fleet statistics: 4.5%**

**Noise Reduction up to -2dB for both departures and arrivals**

- **Average SGO CO2 gains around 4.5%**

1 SGO A/C = 360 tonnes/year = 3000 trees yearly

1000 cars - NOx - CO2

Clean Sky
Systems ITD follows and expands Clean Sky SGO activities

• Management of Trajectory and mission will be included in wider, more integrated cockpit & mission demonstrations

• Management of Aircraft Energy will carry on in WPs dedicated to innovative wing, electrical chain, ... new activities will address other issues in aircraft power management. Demonstrators and test rigs used in Clean Sky will be continued in Clean Sky 2 and completed with new integration environments.

• New areas and target applications are considered: Cabin and cargo systems, Systems for Small Air Transport

• Systems ITD will focus on demonstration and tight integration with IADPs.
Thank you!

Systems for Green Operations
8 years of Technology, Passion, Teamwork, Flexibility and Success!