Climate Impact and Mitigation Concepts

FORUM-AE Workshop

ECATS Conference
Aviation Climate Impact and Mitigation Options

Scope of Conference Session

- **Aviation** contributes to **climate change** and a joint effort is necessary to ensure both **sustainable mobility** and **growth of aviation**.
- However, large **uncertainties** remain when quantifying overall climate change from aviation.
- We focus on contributions which emphasise the need to establish solid **knowledge** and well-evaluated **measures** and means, to provide **quantitative estimates** of aviation climate impact and mitigation concepts.
- Which **approach** is best suited to help aviation identify a durable path into the future?
FORUM-AE COORDINATION ACTION
FP7 European coordination action; GA 605506; 2013-2017

FORUM-AE Overview & Perspectives

EASN Conference, Porto, Oct 2016
Presenter: Sigrun Matthes, DLR
Coordinator: Olivier Penanhoat, Snecma

www.forum-ae.eu
FORUM on Aviation and Emissions (& Environment)

- **FORUM-AE offers a European technical forum addressing:**
  - emissions environmental impacts
  - most-promising mitigation solutions
  - technical recommendations on regulation issues

- Assesses major European RTD programs progress against ACARE environmental goals

- Compiles recommendations in terms of future RTD priorities
PROJECT’S SCOPE AND ORGANISATION

Steering Committee

Coordinator (Snecma)

Project Management Committee (PMC)

WP1
Environmental Impacts
Paul Brok (NLR)
Sigrun Matthes (DLR)

WP2
Mitigation Solutions
Xavier Vancassell (ON)
Olivier Penanhoat (SN)

WP3
Regulation Technical Issues
Bethan Owen (MMU)
Paul Madden (RR)

WP4
Management and Dissemination
Olivier Penanhoat (SN)
Peter Wiesen (ECATS)
WORKSHOPS & MONITORING

Large number of topical workshops:

<table>
<thead>
<tr>
<th>Workshops</th>
<th>Date</th>
<th>Location</th>
<th>Hosting partner</th>
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</thead>
<tbody>
<tr>
<td>Kick-off Workshop</td>
<td>Sept, 19th &amp; 20th 2013</td>
<td>Brussels</td>
<td>EC</td>
</tr>
<tr>
<td>Air Quality Workshop</td>
<td>January, 9th 2014</td>
<td>Manchester, United Kingdom</td>
<td>MMU</td>
</tr>
<tr>
<td>non volatile Particulate Matter (nvPM)</td>
<td>January, 10th 2014</td>
<td>Manchester, United Kingdom</td>
<td>MMU</td>
</tr>
<tr>
<td>Climate Change</td>
<td>April, 2nd &amp; 3rd 2014</td>
<td>Oberpfaffenhofen, Germany</td>
<td>DLR</td>
</tr>
<tr>
<td>CO2 and Fuel Burn Technology</td>
<td>July, 1st 2014</td>
<td>Paris, France</td>
<td>Snecma</td>
</tr>
<tr>
<td>non-CO2 Technology Workshop</td>
<td>July, 2nd 2014</td>
<td>Paris, France</td>
<td>Snecma</td>
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<tr>
<td>Alternative Fuels Workshop (SAFF)</td>
<td>October, 21st 2014</td>
<td>Madrid, Spain</td>
<td>SENASA</td>
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<td>Basket of Measures / MBM</td>
<td>May, 19th 2015</td>
<td>Toulouse, France</td>
<td>Airbus</td>
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<tr>
<td>Basket of Measures / CO2 standard</td>
<td>May, 20th 2015</td>
<td>Toulouse, France</td>
<td>Airbus</td>
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<tr>
<td>Mid-Term Meeting</td>
<td>July, 8th &amp; 9th 2015</td>
<td>Brussels</td>
<td>EC</td>
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<tr>
<td>Inventory Workshop</td>
<td>Sept., 1st &amp; 2nd 2015</td>
<td>Zurich, Switzerland</td>
<td>Zurich Airport</td>
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<td>ATM</td>
<td>19 &amp; 20/01/2016</td>
<td>Paris/Brussels</td>
<td>Eurocontrol</td>
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<td>Air Quality Workshop-bis</td>
<td>April, 14th 2016</td>
<td>Amsterdam</td>
<td>NLR</td>
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<tr>
<td>non volatile Particulate Matter (nvPM)-bis</td>
<td>April, 15th 2016</td>
<td>Amsterdam</td>
<td>NLR</td>
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<tr>
<td>Climate Change-bis (with ECATS 2nd Conf)</td>
<td>November, 8th 2016</td>
<td>Athens</td>
<td>ECATS</td>
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<tr>
<td>non-CO2 Technology Workshop-bis</td>
<td>March, 8th &amp; 9th 2017</td>
<td>Berlin</td>
<td>RRD</td>
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<tr>
<td>CO2 and Fuel Burn Technology + elect. a/c</td>
<td>May 2017 - TBD</td>
<td>Reims</td>
<td>Onera</td>
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<tr>
<td>Final Conference</td>
<td>June 2017 - TBD</td>
<td>Paris</td>
<td>Snecma</td>
</tr>
</tbody>
</table>

Detailed outputs in: [www.forum-ae.eu](http://www.forum-ae.eu)

- General Status / SoA / Statements / RTD priorities / Recommendations
ACARE Environmental Goals by 2050

- CO₂ emissions per passenger kilometre have been reduced by 75%, NOₓ emissions by 90% and perceived noise by 65%, all relative to the year 2000.

- Aircraft movements are emission-free when taxiing.

- Air vehicles are designed and manufactured to be recyclable.

- Europe is established as a centre of excellence on sustainable alternative fuels, including those for aviation, based on a strong European energy policy.

- Europe is at the forefront of atmospheric research and takes the lead in formulating a prioritised environmental action plan and establishes global environmental standards.
GLOBAL ENVIRONMENTAL IMPACT & RECOMMENDATIONS

- Studies show how results vary with different emission inventories
  - sensitivity analysis to emissions inventories are recommended.

- Need for clear documentation of assumptions in future scenarios
  - sensitivity studies on such assumptions are also fully relevant

Aviation NOx in 2006 (left) and resulting Ozone perturbation (right)
GLOBAL ENVIRONMENTAL IMPACT & RECOMMENDATIONS

- **Metric** is still an open key issue.
  - Quantitative estimates should be provided for a set of typical metrics (e.g. RF, ATR, GWP...) to demonstrate sensitivity of results on choice of metric. Then, there is a need of careful selection of calculation methods and metrics, appropriate to the question to be answered.

- **Sources of uncertainties** must be analysed & means for robust decisions under uncertainty must be developed

- **Climate-optimised flight routing** must be further developed,
  - ideally considering the individual weather situation.
  - Interest of climate cost functions, measuring with the appropriate metric the effect of an unit of a given species emitted locally on the climate warming

- **Better correlation between contrail/contrail cirrus properties and particle emissions** is required
  - both for prediction accuracy and for mitigation strategy
The range of technological solutions at aircraft level and engine level, complemented by operational solutions (ATM & flight optimisation), is extremely large, when looking to medium and long term.

- See detailed status & preliminary recommendations on: www.forum-ae.eu
- This ECATS conference provides opportunity to consider in details a selection of mitigation options and what is delivered today and most promising solutions
- Two dedicated FORUM-AE workshops in 2017:
  - Non-CO2 Technology workshop in Berlin (hosted by RRD)
  - FB/CO2 Technology workshop in Reims (hosted by Onera)
Climate modellers perspective on aviation emissions of CO\(_2\) equivalents comprises CO\(_2\), CH\(_4\), NO\(_2\), SF\(_6\), HFCs, CFCs (without gases from the Montreal Protocol)

<table>
<thead>
<tr>
<th>country / sector</th>
<th>emissions 2012 [Tg CO(_2)]</th>
<th>tendency</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>452</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>936</td>
<td></td>
</tr>
<tr>
<td>United Kingdom</td>
<td>579</td>
<td></td>
</tr>
<tr>
<td>internat. aviation</td>
<td>528</td>
<td></td>
</tr>
</tbody>
</table>

*data: unfccc.int*
Challenges

- Increasing transport volume
- Increasing emissions
- But, reduce anthropogenic climate change

Observed globally averaged combined land and ocean surface temperature anomaly 1850–2012

IPCC, 2013

Lee et al., 2009

IPCC, 2013
Atmospheric effects of transport emissions

Emissions

ΔCO₂
ΔH₂O
ΔCH₄
ΔO₃
ΔParticles
ΔClouds

Climate forcings

Direct greenhouse gases
Indirect greenhouse gases
Direct aerosol effect
Clouds
Radiative forcing (RF) from aviation 2005

\[ \Delta T_{\text{surf}} = \lambda \cdot RF \]

Total anthropogenic forcing 1.6 W/m²

Aviation fraction:
- CO₂ 1.6 %
- Total 4.9 %

Lee et al., 2009
Contrails by old and new aircraft

Airbus A340

Boeing B707

Modern aircraft

⇒ more energy for propulsion
⇒ cooler exhaust

Schumann et al., 2000
Contrails can develop into contrail cirrus 
(at suitable conditions)
Radiative forcing (RF) from aviation 2005

$$\Delta T_{\text{surf}} = \lambda \cdot RF$$

Note:
Different base years and different emission data have been used

Indirect effects on cirrus clouds?
Weighing the non-CO$_2$ effects

- **Fixed multiplier for the CO$_2$ emissions?**
  - no incentive to work on the non-CO$_2$ effects
  - multiplier does not account for different aircraft or different flight trajectories

- **Radiative forcing (RF)?**
  - RF is a measure of the emissions of the past

- **Global warming potential (GWP)?**
  - used in the Kyoto Protocol to calculate CO$_2$ equivalents
  - does not account for the heat capacity of the climate system
  - problems the short-lived climate forcers

- **Average temperature response (ATR)?**
  - accounts for both, short-lived and long-lived climate forcers
  - provides consistent results for pulse emissions and longer emission scenarios

\[
AGWP = \int_0^H RF_{spec}(t) dt
\]

\[
ATR = \frac{1}{H} \int_0^H \Delta T(t) dt
\]
How can we mitigate the climate impact of aviation?

Focus more on emissions:

- Reduction of the specific emissions
- Reduction of the absolute emissions

Focus more on impact of emissions:

- Climate optimized aircraft
- Eco-efficient flight trajectories
Impact of alternative fuels
Less soot ➜ Impact on contrails

- alternative fuels
- less emissions of soot
- smaller number of initial ice particles in contrails
- change of micro-physical and optical properties of contrails and contrail cirrus
- change of life-time and climate impact of contrails and contrail cirrus

ECATS Conference 2016

ECATS, 08.11.2016

Bock, 2014
Impact of unit "emissions" as function of latitude and altitude of emission

RF from H₂O

RF from contrails

RF from O₃

CH₄ lifetime change
Climate impact of aviation – CO₂ and more

Aviation significantly contributes to climate change.

The impact of the non-CO₂ effects is particularly large for aviation.

The impact of the non-CO₂ effects depends on location, altitude and time of emissions.

Mitigation options reduce aviation emissions, aviation emission climate impact or both.

E.g. alternative fuels can reduce both the contribution to CO₂ and the non-CO₂ emission, hence overall climate impact.

E.g. The non-CO₂ effects can be substantially reduced by flying according to eco-efficient flight trajectories, at a small increase of DOC, via reducing climate impact of emissions.
Climate impact workshop
Impacts and Mitigation Options

• Atmospheric impacts
  • Chair/Rapporteur: Sigrun Matthes / Etienne Terrenoire
    – Intro: Climate impact of aviation
    – Climate impact of CO₂ emissions (Etienne Terrenoire)
    – IMPACT project (Didier Hauglustaine)
    – Climate impact of contrail and contrail cirrus (Lisa Bock)
    – Chemical impacts of aviation emissions (Volker Grewe)
    – Alternative routing: Climate impact mitigation studies (Sigrun Matthes)

• Technology mitigation options
  • Chair/Rapporteur: Didier Hauglustaine / Ling Lim
    – Greener by design (John Green)
    – Emission and mitigation concepts (Paul Madden)
    – Flame stabilisation aerodynamics (Panayotis Koutmos)
    – Intercooled recuperation aero engine (Dimitrios Misirlis)
    – Assessment of PM emissions from engines (Olivier Penanhoat)
    – Strut-braced Wing concepts and a/c configuration (Florian Linke)
    – Drag reduction in aircraft wings (Zinon Vlaxostergios)
    – Aircraft level assessment of contrail mitigaiton (Jean-Charles Khou)
CONTEXT: NEW INTERNATIONAL REGULATION

➔ 2 New international certification standards on aviation emissions in 2016!
   ▪ With an application date after 1st January 2020

➔ CO2 standard:
   ▪ Applying to TF & TP commercial aircrafts

➔ non Volatile Particulate Matter (nvPM) standard:
   ▪ Applying to all in production turbofans above 26.7kN
Key pollutants linked to Air Quality (AQ): NO2 & particles.

- Particles issue to be addressed both in PM2.5 and ultra fine particles (UFP) for which number concentration appears more relevant
- SO2 from the aircraft engine may be important contributor to PM2.5

Strong regulation framework exists:

- At emission source level, workplace level, ambient AQ level
- However nothing yet for APUs => strong uncertainty on their emission factors

Measurements in Europe of PM10 & PM2.5 in airport vicinity are well harmonised and demonstrate a good quality level

- Nevertheless no such exercise done for UFPs
PM2.5 mass concentrations linked to airport activities appear:

- most of the time small compared to PM2.5 coming from other sources
- & very small against AQ limits
- UFPs from airport activities may be a stronger concern with elevated concentrations potentially observed (this should be perhaps verified however on a more representative number of airports?)
Airport emissions inventory and AQ modelling improvements are required to predict more accurately concentrations at and around airports:

- Better knowledge of emissions sources, performance based modelling, benchmarking (generic CAEPport), validation against field measurements...
- Better nvPM emissions factors; potential improvement of FOA3; UFP dispersion modelling

<table>
<thead>
<tr>
<th>Source</th>
<th>Activity</th>
<th>Emission factor</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircraft engine</td>
<td>Stop&amp;go behaviour, Idle vs taxi, flex take-off</td>
<td>ICAO Emissions Data Bank (EDB); PM is work in progress</td>
<td>Fuel Flow Method (e.g. Boeing 2 FFM); First Order Approx. (FOA3) for nvPM &amp; PM2.5</td>
</tr>
<tr>
<td>APU</td>
<td>Duration for Environmental Control System (ECS)</td>
<td>Very coarse in Doc 9889</td>
<td>Simple product.</td>
</tr>
<tr>
<td>Aircraft frame</td>
<td>Brakes, tires</td>
<td>Assumptions</td>
<td>Simple product.</td>
</tr>
<tr>
<td>GSE</td>
<td>Inventory good, else poor</td>
<td>EU Non-Road Mobile Machinery (EUNRMM) emissions &amp; standards</td>
<td>Simple product.</td>
</tr>
<tr>
<td>Stationary Sources</td>
<td>Usually well known</td>
<td>EMEP-EEA guidance, manufacturer data</td>
<td>Simple product.</td>
</tr>
<tr>
<td>Landside vehicles</td>
<td>Fair, lots of assumptions</td>
<td>Handbook Emission Factors for Road Transport (HBEFA), EEA COPERT, etc.</td>
<td>Simple product.</td>
</tr>
</tbody>
</table>

Status & Identified Gaps in Airports Inventory
Mitigation Technology
Status & Key Priorities for Future Research in Europe
### Status against ACARE goals

<table>
<thead>
<tr>
<th>Reference 2000</th>
<th><strong>ACARE 2020 Goals</strong> (at TRL6)</th>
<th><strong>ACARE 2050 Goals</strong> (at TRL6)</th>
<th><strong>FORUM-AE Assessment (2015)</strong> (extrapol. at TRL6 in 2020)</th>
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<tr>
<td></td>
<td>High Level</td>
<td>detailed (SRA)</td>
<td>High Level</td>
</tr>
<tr>
<td><strong>CO2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&quot;-50% per pass km&quot;</td>
<td>aircraft: -20% to -25%</td>
<td>engine: -15% to -20%</td>
</tr>
<tr>
<td><strong>NOx</strong> (LTO)</td>
<td>&quot;-80%&quot;</td>
<td>engine: -60% CAEP6; complement achieved by aircraft + ATM</td>
<td>&quot;-90%&quot;</td>
</tr>
<tr>
<td>Representative technology of aircraft &amp; engine with 2000 EIS, &amp; representative 2000 ATM</td>
<td>Achieved through -50% Fuel Burn &amp; -60% cruise EINoX reduction</td>
<td>&quot;-90%&quot;</td>
<td>Achieved through -75% Fuel Burn &amp; further cruise EINoX reduction</td>
</tr>
<tr>
<td><strong>NOx</strong> (Cruise)</td>
<td>&quot;-80%&quot;</td>
<td>&quot;damaging emissions reduced&quot;</td>
<td>emissions qualitatively reduced (particles, CO, UHC) and better understanding of impacts</td>
</tr>
<tr>
<td><strong>Other emissions</strong></td>
<td></td>
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</table>
ACARE 2050 very challenging CO2 reduction objective would permit to mitigate substantially the effect of traffic growth.

- So, it is essential to pursue a tremendous effort at the aircraft level, the engine level and the ATM & flight operation level in order to progress towards this ambitious goal.

Unconventional configurations like aircrafts equipped with CROR concept or UHBPR concepts, must be further developed.

- Their mitigation potential, complemented with laminar wing benefit, must be maximised and their maturity must be pushed over TRL5.
RECOMMENDATIONS & NEEDS (CO2 MITIGATION SOLUTIONS)

- Aircraft/Engine technologies must be further and continuously improved
  - both for evolutionary aircraft/engine applications and longer term disruptive ones

- More radically unconventional solutions (distributed propulsion a/c…) should be also considered for much longer term and at lower TRL

DISPURSAL Project Analysis
Consensus appears that fine particles (nvPM) reduction must be also achieved, in addition to NOx. This induces critical R&T on:

- **The combustor technology itself in order to reduce both NOx & nvPM**
  - enhanced lean combustion in general (achieving TRL6 maturity & extending its application to smaller size and/or smaller OPR engine combustors),
  - focus on more specific aspects which may be beneficial to particles reduction

Lean combustion technology: Snecma calculation (left), Rolls-Royce solution (right)
The modeling of emissions (NOx + particles),

- Modelling for particles is far from being predictable today, because of the physical complexity of particles formation and of the modeling of combustion related operability aspects

The experimental analysis, which is absolutely necessary to support modeling development or to assess technology.

- This assumes advanced measurements (in particular intrusive and non intrusive measurements of particles in the combustion chamber)
- and appropriate test capability (from multi-sector tests to full annular tests, with ability to achieve high pressure levels)
RECOMMENDATIONS & NEEDS (ALTERNATIVE FUELS)

- Harmonisation is needed to converge on a common and technically satisfactory CO2 LCA methodology in order to assess alternative jet fuel production pathways.

- The aromatic content of future jet fuels (fossil or renewable) should be minimized as much as possible in order to reduce particles emission. Reduction of sulphur content will be also beneficial.

- Need to develop predictive tools to model the fuel interaction with the aircraft fuel system or with the engine. => fuel composition optimisation to improve fuel compatibility and help reducing ASTM certification costs.
FORUM-AE support to ACARE WG3 & Contribution to SRIA up-date
Technical inputs (status & recommendations) are provided periodically to ACARE WG3. Participation to the ACARE WG3 meetings is ensured by the FORUM-AE project’s coordinator and (or delegated to one of the) individual FORUM-AE partners representatives.

Inputs are strictly based on the conclusions agreed inside FORUM-AE.

A contribution to the SRIA up-date was provided before the summer but the work must be pursued more accurately in order to be sure the content is consolidated by FORUM-AE.
ACARE SRIA UPDATE 2017

**SRIA Challenge 3 – Protecting the environment and the energy supply**

- 3.1 - Defining air vehicles of the future: evolutionary steps
- 3.2 - Defining air vehicles of the future: revolutionary steps
- 3.3 - Increasing material recycling and re-use
- 3.4 - Improving air operations and traffic management
- 3.5 - Improving the airport environment
- 3.6 - Providing necessary quantity of affordable alternative energy sources
- 3.7 - Understanding aviation's climate impact
- 3.8 - Adaptation to climate change
- 3.9 - Providing appropriate regulation and incentives

FORUM-AE input from WP on

↔ Mitigation  ↔ Mitigation  ↔ Impacts  ↔ Mitigation  ↔ Impacts  ↔ Mitigation  ↔ Impacts  ↔ Mitigation  ↔ Regulation
Conclusions & Perspectives
CONCLUSIONS & PERSPECTIVES

➢ FORUM-AE delivered in July 2015 its mid-term report, containing a first complete status and identifying research priorities linked to:
  - Aviation Emissions Environmental Impact
  - Mitigation Solutions (Technology/ATM/ Alternative Fuels)
  - Regulation issues

➢ Since then, this status was partially consolidated and 3 forthcoming major workshops (on Climate Change / on Combustor Technology/ on Aircraft & engine Technology) will provide complementary material. Monitoring of relevant projects (see appendix) is a permanent task.

➢ On this base, R&T strategy for the future will be recommended:
  - To ACARE WG3, including SRIA update 2017
  - In the project’s final synthesis (July 2017)

➢ Potential network follow-up is currently evaluated
Thank You!
Very large number of relevant projects

<table>
<thead>
<tr>
<th>PROJECT</th>
<th>T0</th>
<th>STATUS</th>
<th>Coordinator</th>
<th>TITLE</th>
<th>TYPE</th>
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<tbody>
<tr>
<td>REACT4C</td>
<td>2010</td>
<td>Completed</td>
<td>DLR⁹</td>
<td>Reducing Emissions from Aviation by Changing Trajectories for the Benefit of Climate</td>
<td>Impacts</td>
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<td>ECATS</td>
<td>2005</td>
<td>Foundation</td>
<td>ECATS⁹</td>
<td>Environmental Compatible Air Transport System =&gt; Foundation</td>
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<td>MOZAIC</td>
<td>1994</td>
<td>On-going</td>
<td>RC Jülich</td>
<td>Measurement of Ozone, Water Vapor, Carbon Monoxide, Nitrogen Oxide by Airbus In-Service Aircraft</td>
<td>Impacts</td>
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<td>On-going</td>
<td>RC Jülich</td>
<td>In service Aircraft for a Global Observing System</td>
<td>Impacts</td>
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<td>IAGOS ERI</td>
<td>2009</td>
<td>On-going</td>
<td>RC Jülich</td>
<td>In service Aircraft for a Global Observing System / European Research Infrastructure</td>
<td>Impacts</td>
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<td>CARIBIC</td>
<td>2004</td>
<td>On-going</td>
<td>MPI Chemie, Mainz</td>
<td>Civil aircraft for the regular investigation of the atmosphere based on an instrument container</td>
<td>Impacts</td>
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<td>QUANTIFY</td>
<td>2005</td>
<td>Completed</td>
<td>DLR⁹</td>
<td>Quantifying the Climate Impact of Global and European Transport Systems</td>
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<td>CleanSky - SFWA</td>
<td>2008</td>
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<td>SMART Fixed Wing Aircraft</td>
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<td>CleanSky - GRA</td>
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<td>On-going</td>
<td>Alenia</td>
<td>The Green Regional Aircraft</td>
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<td>Eurocopter</td>
<td>Green Rotorcraft</td>
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<tr>
<td>NACRE</td>
<td>2005</td>
<td>Completed</td>
<td>Al⁹</td>
<td>New Aircraft Concepts Research</td>
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<td>AHEAD</td>
<td>2011</td>
<td>On-going</td>
<td>TU Delft</td>
<td>Advanced Hybrid Engines for Aircraft Development</td>
<td>Aircraft</td>
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<td>DISPURSAL</td>
<td>2013</td>
<td>On-going</td>
<td>Bauhaus</td>
<td>Distributed Propulsion and Ultra-high By-pass Rotor Study at Aircraft Level</td>
<td>Aircraft</td>
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<td>CleanSky - SAGE</td>
<td>2008</td>
<td>On-going</td>
<td>RR⁹&amp;SN⁹</td>
<td>Sustainable And Green Engine</td>
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<td>DREAM</td>
<td>2008</td>
<td>Completed</td>
<td>RR⁹</td>
<td>Validation of Radical Engine Architecture systeMs</td>
<td>Engine &amp; Fuel</td>
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<tr>
<td>NEWAC</td>
<td>2006</td>
<td>Completed</td>
<td>MTU</td>
<td>NEW Aero engine Core concepts</td>
<td>Engine HP</td>
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<td>VITAL</td>
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<td>Completed</td>
<td>SN⁹</td>
<td>Environmentally Friendly Aero-Engine</td>
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<td>LEMCOTEC</td>
<td>2011</td>
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<td>RRD⁹</td>
<td>Low Emissions Core-Engine Technologies</td>
<td>Engine BP</td>
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<td>EBREAK</td>
<td>2012</td>
<td>On-going</td>
<td>TM⁹</td>
<td>Engine Breakthrough components and subsystems</td>
<td>Engine</td>
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<tr>
<td>ENOVAL</td>
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<td>On-going</td>
<td>MTU</td>
<td>The Engine mOdule Validators</td>
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</table>
## Monitoring activity (continued)

<table>
<thead>
<tr>
<th>Project</th>
<th>Year</th>
<th>Status</th>
<th>Description</th>
<th>Sector</th>
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</thead>
<tbody>
<tr>
<td>KIAI</td>
<td>2009</td>
<td>Completed</td>
<td>Knowledge for Ignition, Acoustics and Instabilities</td>
<td>Combustor</td>
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<tr>
<td>FIRST</td>
<td>2010</td>
<td>On-going</td>
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<td>Combustor</td>
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<td>FACTOR</td>
<td>2010</td>
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<td>IMPACT-AE</td>
<td>2011</td>
<td>On-going</td>
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<td>Combustor</td>
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<tr>
<td>TECG-AE</td>
<td>2008</td>
<td>Completed</td>
<td>SN* Technology Enhancements for Clean Combustion</td>
<td>Combustor</td>
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<tr>
<td>INTELL ECT D.M.</td>
<td>2003</td>
<td>Completed</td>
<td>RRD* Integrated Lean Low-Emission Combustor Design Methodology</td>
<td>Combustor</td>
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<tr>
<td>TIMECOP-AE</td>
<td>2006</td>
<td>Completed</td>
<td>TM* Toward Innovative Methods for Combustion Prediction in Aero-engines</td>
<td>Combustor</td>
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<td>TLC</td>
<td>2005</td>
<td>Completed</td>
<td>SN* Towards Lean Combustion</td>
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<tr>
<td>LOPOCOTEPE</td>
<td>2000</td>
<td>Completed</td>
<td>SN* Low Pollutant CCmbustor TEC Technology Project</td>
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<tr>
<td>ALFA-BIRD</td>
<td>2003</td>
<td>Completed</td>
<td>Eu-Vri Alternative Fuels and Biofuels for Aircraft Development</td>
<td>Fuel</td>
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<td>SWAFEA</td>
<td>2009</td>
<td>On-going</td>
<td>ONERA Sustainable Way for Alternative Fuels and Energy in Aviation</td>
<td>Fuel</td>
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<tr>
<td>burnFAIR</td>
<td>2010</td>
<td>On-going</td>
<td>LI* Searching for a viable kerosene replacement</td>
<td>Fuel</td>
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<tr>
<td>ITACA</td>
<td>2012</td>
<td>On-going</td>
<td>SEN* Initiative Towards Sustainable Kerosene for Aviation</td>
<td>Fuel</td>
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<td>SESAR</td>
<td>2007</td>
<td>On-going</td>
<td>JU Single European Sky ATM Research</td>
<td>Operations</td>
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<td>CleanSky-SGO</td>
<td>2008</td>
<td>On-going</td>
<td>Theles System for Green Operation</td>
<td>Operations</td>
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<tr>
<td>AIRE</td>
<td>2009</td>
<td>On-going</td>
<td>SJU-FAA Atlantic Interoperability Initiative to Reduce Emissions</td>
<td>Operations</td>
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<tr>
<td>ERAT</td>
<td>2007</td>
<td>Completed</td>
<td>Tu70 Environmental Responsible Air Transport</td>
<td>Operations</td>
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<td>CS-EcoDesign</td>
<td>2005</td>
<td>On-going</td>
<td>DASFMF Eco-Design (co-led by Dassault &amp; Fraunhofer)</td>
<td>Recyclability</td>
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<td>CleanSky-TE</td>
<td>2003</td>
<td>On-going</td>
<td>Theles Technology Evaluator</td>
<td>Assessment</td>
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<tr>
<td>AERONET III</td>
<td>2003</td>
<td>Completed</td>
<td>DLR* Aircraft Emissions and Reduction Technologies</td>
<td>Network &amp; monitoring</td>
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<tr>
<td>X.NOISE EV</td>
<td>2010</td>
<td>On-going</td>
<td>SN* Aviation Noise Research Network and Coordination</td>
<td>Network &amp; monitoring for NOISE</td>
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<td>COREJet-fuel</td>
<td>2013</td>
<td>On-going</td>
<td>FNR Coordinating research and innovation of jet and other sustainable aviation fuel</td>
<td>Network &amp; monitoring for Fuel</td>
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<tr>
<td>Team-Play</td>
<td>2010</td>
<td>Completed</td>
<td>DLR* Tool Suite for Environmental and Economic Aviation Modelling for Policy Analysis</td>
<td>Regulation</td>
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<td>NEPAIR</td>
<td>2003</td>
<td>Completed</td>
<td>Cinetiq Development of the technical basis for a New Emissions Parameter covering the whole AIRcraft</td>
<td>Regulation</td>
</tr>
</tbody>
</table>

**Soprano: kick-off in Sept 2016**
PROJECT’S SCOPE AND ORGANISATION

Steering Committee

Coordinator (Snecma)

Project Management Committee (PMC)

WP1: Environmental Impacts
  - Paul Brok (NLR)
  - Sigrun Matthes (DLR)

WP2: Mitigation Solutions
  - Xavier Vancassel (ON)
  - Olivier Penanhoat (SN)

WP3: Regulation Technical Issues
  - Bethan Owen (MMU)
  - Paul Madden (RR)

WP4: Management and Dissemination
  - Olivier Penanhoat (SN)
  - Peter Wiesen (ECATS)
European and Environment RTD community

FORUM-AE

- Academic and Industrial partners
- Workshops and Monitoring
- Expertise

Other Coordination and Support Actions

Public

ICAO/CAEP
EASA
Agencies
EU

CORE-JetFuel
CATER
X-NOISE
Carpadocia
Optics

FORUM-AE Overview
Regulation Technical Status