INDUSTRIAL RESEARCH

SESAR Environment Assessment Process

Deliverable ID:	4.0.080
Dissemination Level:	[PU/CO/CL]
Project Acronym:	PJ19.4.2
Grant:	731765
Call:	H2020-SESAR-2015-2]
Topic:	Content Integration
Consortium Coordinator:	EUROCONTROL]
Edition Date:	23 September2019]
Edition:	[04.00.00]
Template Edition:	02.00.01

Founding Members

EUROPEAN UNION EUROCONTROL

Authoring & Approval

Authors of the document

Name/Beneficiary	Position/Title	Date
Jean-François Sciabica	Airbus Contributor	11/05/2016
Adrien Jeandel	Airbus Contributor (AVTECH)	04/11/2014
David Alvord	Airbus Contributor (AVTECH)	04/11/2014
Gregor Thamm	DFS Contributor	11/05/2016
Matthias Hark	DFS Contributor	11/05/2016
Stefan Schwanke	DFS Contributor	11/05/2016
Romain Troit	DSNA Contributor	04/11/2014
Eduardo Milanés de la Loma	ENAIRE Contributor	11/02/2016
María Sánchez Sampedro	ENAIRE Contributor	04/11/2014
Giovanni Riccardi	ENAV Contributor (SICTA)	11/05/2016
Luisa De Francesco	ENAV Contributor (SICTA)	04/11/2014
Giuseppe Romano	ENAV Contributor	11/05/2016
Teresa Di Lallo	ENAV Contributor	11/05/2016
David Brain	EUROCONTROL Contributor	11/05/2016
Elsa Freville	EUROCONTROL Contributor	04/11/2014
Laurent Box	EUROCONTROL Contributor	11/05/2016
Laurent Cavadini	EUROCONTROL Contributor	11/05/2016
Laurent Tabernier	EUROCONTROL Contributor	11/05/2016
Mark Whiteley	EUROCONTROL Contributor	04/11/2014
Nuria Torres-Meana	EUROCONTROL Contributor	04/11/2014
Peter Hullah	EUROCONTROL Contributor	11/05/2016
Rachel Burbidge	EUROCONTROL Contributor	11/05/2016
Robin Deransy	EUROCONTROL P16.06.03 Project Manager, Content coordinator	11/05/2016
Ian Jopson	NATS contributor	04/11/2014
Timothy Gill	NATS Contributor	04/11/2014
Merlijn den Boer	NLR Contributor, Content coordinator	11/05/2016
Roel Hogenhuis	NLR Contributor	11/05/2016
Henrik Ekstrand	Novair Contributor	11/05/2016

Peter Larsson	Novair Contributor	04/11/2014
Ulrika Ziverts	Novair Contributor, Content coordinator	04/11/2014
Henrik Jonshammar	Scandinavian Airlines Contributor	04/11/2014
Sofia Souihi	Thalès Contributor	04/11/2014

Reviewers internal to the project

Name/Beneficiary	Position/Title	Date
All persons mentioned above	As mentioned above	04/11/2014 & 11/05/2016

Approved for submission to the SJU By - Representatives of beneficiaries involved in the project

Name/Beneficiary	Position/Title	Date
Robin Deransy	EUROCONTROL 16.06.03 Project leader	11/05/2016
Robin Deransy	EUROCONTROL PJ19.04.02 Environment Focal Point	22/03/2019

Rejected By - Representatives of beneficiaries involved in the project

Name/Beneficiary	Position/Title	Date
None		

Document History

Edition	Date	Status	Author	Justification
00.00.01	15/05/2011	Original draft	Robin Deransy – Mark Whiteley	Split of original D06 – ENV Handbook in two parts.
00.00.02	23/03/2012	Draft	Robin Deransy – Mark Whiteley	Adoption of ERM level 1 process and expansion
00.00.03	11/04/2012	Final	Robin Deransy – Mark Whiteley – Nuria Torres-Meana	Quality check and integration of F2F and Webex reviews
01.00.00	08/03/2013	Final v1	ECTL + Thalès + All	Update following review of 2012 applicability of 16.03.X projects deliverables
01.00.09	14/05/2014	Draft	All	Completely new edition
02.00.00	04/11/2014	Final v2	All	Completely new edition
02.00.01	29/01/2015	Final v2.1	All	Integration of SJU comments

03.00.00	12/05/2016	Final 3.0	All	Integration of last F2F and SJU comments
04.00.00	23/09/2019	Final 4.0	Robin Deransy	Update of version 3.0

PJ19.4.2

PJ19

This [insert type of result] is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 731765 under European Union's Horizon 2020 research and innovation programme.

Abstract

This document presents a common approach for performing environmental impact assessments in SESAR.

Its intended audience is primarily the people responsible for carrying out the environmental impact assessments associated with operational validation exercises.

Following the guidance set out in this document will greatly facilitate the collection of evidence/information about impacts on the environment of the operational concepts validated by SESAR and their integration into environmental impact assessment documents at aggregated levels.

This version is the updated version of the final published under the SESAR 1 programme and will serve as the basis for the environmental assessment methodology to be used in SESAR2020.

Table of Contents

List of Tables

List of Figures

1 Introduction

1.1 Background

The main challenge for aviation's global environmental policy is to ensure that the growth in air traffic remains sustainable from an environmental point of view. If no action is taken, Carbon Dioxide (CO_2) emissions from international aviation could grow by as much as 3 times above 2005 levels in 2050[(1)]. Aviation is also a major source of Nitrogen Oxides (NOx) and Particulate Matter (PM). Increasing numbers of people are complaining about poor air quality near to airports and the rise in concentrations of fine PM is a growing source of concern for public health. Air traffic noise around airports affects some 2.5 million citizens in Europe[(2)] and, as well as creating much annoyance, is a cause of sleep disturbance and health problems.

Despite the fact that aviation only contributes to 2 to 3% of man-made CO_2 emissions, as demand for air transport grows, the aviation industry is committed to further reducing its CO_2 emissions. Figure 1 shows, schematically, how the aviation industry expects to reduce CO_2 emission by -50% in 2050 compared to 2005. A mix of measures is required, combining improvements in technology, operations, infrastructure, and additional technologies and biofuels, which make up the largest contributor. Note also the period of about twenty years between 2020 and 2040 where market-based measures will be required in order to maintain commitments.

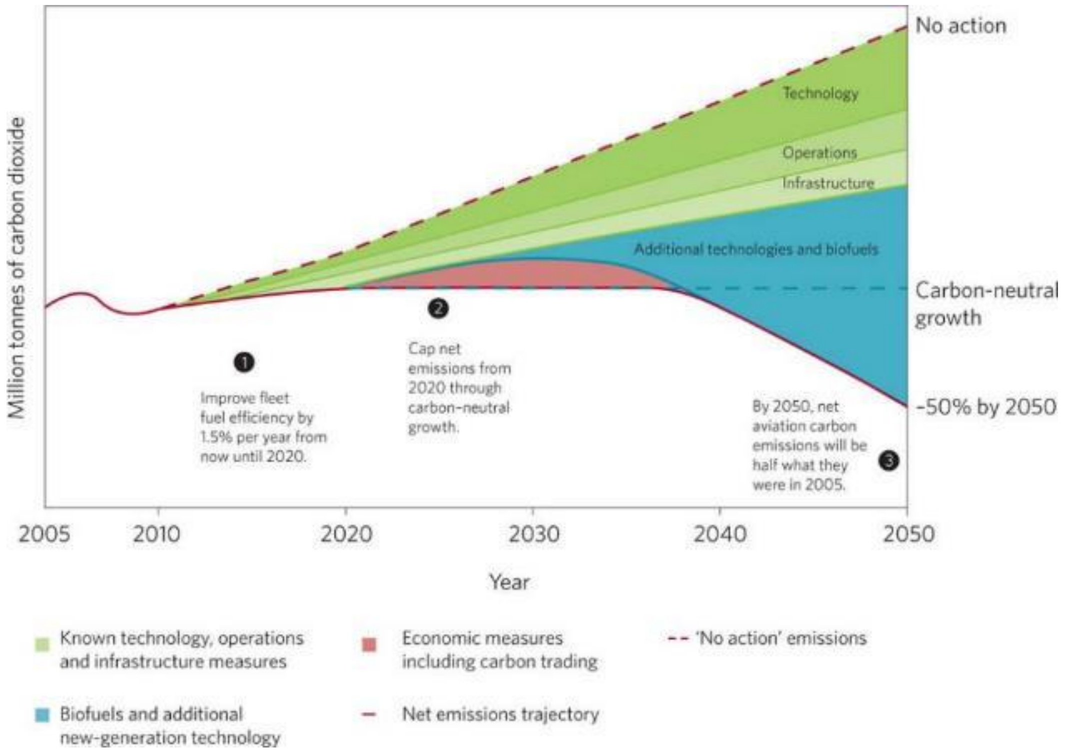


Figure 1: Expected long term CO2 emissions forecast and actions, source ATAG

[1] Based on an average 2.5% increase in traffic per year (STATFOR).
[2] See European Commission Memo/14/282.

Although only between 6 to 12%[3] of aviation emissions are attributable to ATM, the reduction in environmental impact has been defined as one of the main performance requirements of SESAR. Every project in SESAR must, where possible, play its part in meeting the programme's environmental objectives. The environmental impact is determined with environmental impact assessments. The information obtained will become particularly valuable to support the business case when the ATM changes near the deployment phase and public opinion could become an obstructing factor. Therefore, SESAR deployment planning that may change environmental conditions around airports should take local decision making and consultation into account. By engaging with local stakeholders and communities proactively, the risk of local opposition to operational changes can be reduced.

ⓘ	The European Commission defines an environmental assessment as a procedure that ensures that the environmental implications of decisions are taken into account before the decisions are made. Environmental assessment can be undertaken for individual projects, on the basis of Directive 2011-92-EU (known as 'Environmental Impact Assessment' – EIA Directive) or for public plans or programmes on the basis of Directive 2001-42-EC (known as 'Strategic Environmental Assessment' – SEA Directive). The common principle of both Directives is to ensure that plans, programmes and projects likely to have significant effects on the environment are made subject to an environmental assessment, prior to their approval or authorisation. Consultation with the public is a key feature of environmental assessment procedures[4].

SESAR has adopted the performance-driven approach advocated by the European Operational Concept Validation Methodology (E-OCVM). As part of this approach, one of the main performance requirements of SESAR is to assess and quantify the potential benefits that the SESAR concept will bring in terms of fuel and CO_2 savings.

The SESAR performance ambitions are defined in the European ATM Master Plan[5]. As can be seen on Figure, the performance ambition for Environment has been set between of 5 to 10% fuel saving per flight at 2035 compared with a 2012 baseline.

However, the assessment of the environmental impacts and potential environmental benefits of the SESAR concept should not be limited to fuel and CO_2 savings. Although no official targets have been set for noise and local air quality, these two environmental aspects should also be included in the environmental assessment as they might become blocking factors for the deployment phase of SESAR. Recognising that some airports are already bound by significant noise regulations and some of them have introduced restrictions to avoid pollution, SESAR should not only achieve fuel savings and emissions reductions but also ensure that noise impact is not worsened and preferably improved. The additional aims on noise and local air quality are called SESAR environmental objectives in this document.

At a local level, there may be interdependencies between these environmental impacts such that the reduction of one impact may come at the cost of increasing another. Without any overall performance framework to prioritise the mitigation of these impacts, public perception is often the determining factor in local environmental regulation, and has the potential to alter the performance of the ATM network in this area. This is particularly significant where noise and CO_2 have to be traded as the

[3] IPCC 1999
[4] http://ec.europa.eu/environment/eia/review.htm
[5] https://www.atmmasterplan.eu/downloads/

immediacy and tangibility of noise impacts have led to a strong public focus on this issue, which can jeopardise the delivery of CO_2 benefits from the new concept to be deployed. While SESAR does not manage this implementation phase, it is providing advice and guidance on how to consider interdependencies at a local level so that SESAR environmental objectives are met.

Key Performance Area	SES high-level goals vs. 2005	Key Performance Indicator	Baseline value (2012)	Ambition value (2035)	Performance ambition vs. baseline: Absolute improvement	Performance ambition vs. baseline: Relative improvement
Capacity	Enable 3-fold increase in ATM capacity	Departure delay[4], min/dep	9.5 min	6.5-8.5 min	1-3 min	10-30%
		IFR movements at most congested airports[5], million	4 million	4.2-4.4 million	0.2-0.4 million	5-10%
		Network throughput IFR flights[5], million	9.7 million	~15.7 million	~6.0 million	~60%
		Network throughput IFR flight hours[5], million	15.2 million	~26.7 million	~11.5 million	~75%
Cost efficiency	Reduce ATM services unit cost by 50% or more	Gate-to-gate direct ANS cost per flight[1], EUR(2012)	EUR 960	EUR 580-670	EUR 290-380	30-40%
Operational efficiency		Gate-to-gate fuel burn per flight, kg/flight	5280 kg	4780-5030 kg	250-500 kg	5-10%
		Additional gate-to-gate flight time per flight[2], min/flight	8.2 min	3.7-4.1 min	4.1-4.5 min	50-55%
		(Within the: Gate-to-gate flight time per flight[3], min/flight)	(111 min)	(116 min)		
Environment	Enable 10% reduction in the effects flights have on the environment	Gate-to-gate CO_2 emissions, tonnes/flight	16.6 tonnes	15-15.8 tonnes	0.8-1.6 tonnes	5-10%
Safety	Improve safety by factor 10	Accidents with direct ATM contribution[6], #/year Includes in-flight accidents as well as accidents during surface movement (during taxi and on the runway)	0.7 (long-term average)	no ATM related accidents	0.7	100%
Security	-	ATM related security incidents resulting in traffic disruptions	unknown	no significant disruption due to cyber-security vulnerabilities	unknown	-

1 Unit rate savings will be larger because the average number of Service Units per flight continues to increase.
2 "Additional" here means the average flight time extension caused by ATM inefficiencies
3 Average flight time increases because the number of long-distance flights is forecast to grow faster than the number of short-distance flights
4 All primary and secondary (reactionary) delay, including ATM and non-ATM causes
5 Includes all non-segregated unmanned traffic flying IFR, but not the drone traffic flying in airspace below 500 feet or the new entrants flying above FL 600
6 In accordance with the PRR definition: where at least one ATM event or item was judged to be DIRECTLY in the causal chain of events leading to the accident. Without that ATM event, it is considered that the accident would not have happened

Figure 2: Performance ambitions for 2035 for controlled airspace, Source: ATM Master Plan 2019.

There is often also a trade-off between the environment and other performance areas where other considerations may exist, such as in the case of aviation, airspace capacity or economic considerations. It is not the role of this document, however, to provide an insight into how these non-environmental trade-offs should be managed.

1.2 SESAR 2020

SESAR Solutions contain outputs of the R&D Activities and relate to either an Operational Improvement (OI) step or a group of OI steps with their Enablers (technical system, procedure or human), which have been designed, developed and validated in response to Validation Targets and that will deliver business benefit to European ATM when put into operation.

Validated SESAR Solutions are defined and described by a set of documentation called SESAR deliverables (operational requirements, assumptions, design decisions, design-architecture material, prototypes and validation platforms, etc.).

SESAR solutions are supported by:

- A clearly defined measurable operational improvement and success metric;

- Technical specification of necessary systems in the aircraft and on the ground;
- Set of inputs and requirements for standards-regulation and procedures for both airborne and ground systems;
- Business cases built upon appropriate Deployment Packages (DPs) and Deployment Scenarios (DSs)

For more information, please refer to the SESAR Work Programme.

1.3 Purpose of the document

This document presents a common approach to performing Environmental Impact Assessments (EIAs) in SESAR. This common approach is vital in SESAR to ensure the compatibility of different assessments and that the overall environmental impact of SESAR-related deployments can be estimated. The document may also be used to as a guideline to assess the performance change resulting from any airspace change proposal. While it is important to this objective that these results be standardised and if possible aggregated up to the entire ECAC area, - local factors may in many cases limit such standardisation and aggregation. Therefore, they are also addressed in this document.

The collection of evidence-information about the potential impacts a SESAR-validated operational concept will have on the environment will be greatly facilitated by following the recommendations made in this document.

1.4 Intended readership

This document is intended for people involved in carrying out the environmental impact assessment of operational validation exercises.

1.5 Pictograms used in this document

ⓘ	Important information
💣	Attention!

1.6 Glossary of terms

Term	Definition
16.03.01	The SESAR 1 research project responsible for the development of the SESAR environmental validation framework (methods, models, tools)
16.03.02	The SESAR 1 research project responsible for defining environmental metrics

Term	Definition
16.03.03	The SESAR 1 research project responsible for developing a framework to establish interdependencies vs. other performance areas
16.03.07	The SESAR 1 research project responsible for defining future regulatory scenarios and impacts
16.06.03	The SESAR 1 transversal project responsible for the “Environment Support And Coordination" function
16.06.06	The SESAR 1 transversal project responsible for “Business Case maintenance, support and coordination”
Benefit and Impact Mechanism	A cause-effect description of the impacts of the solution proposed by a project. It describes the positive and the negative impacts that the project solution is expected to provide or demonstrate.
Benefit Diagram	A Benefit and Impact Mechanism is usually shown in a diagram giving an overview of the links between the (new) features that the project is bringing to the world of ATM and indicators (aspects which can be measured or calculated from other metrics), Positive or Negative Impacts for each performance area, and Key Performance Areas (KPAs) or Key Performance Indicators (KPIs). This diagram is supplemented by textual descriptions of the feature, the numbered links and impacts.
Business Case	A Business Case is a tool for decision-makers; it aims to provide them with the information they need to make a fully informed decision on whether funding should be provided and/or whether an investment should proceed. A Business Case is much more than just a financial analysis as it also includes quantitative and qualitative arguments on performance and transversal activities that are key elements to determining the value of the project.
Deployment Scenario	Deployment Scenario consists of a set of SESAR Solutions selected to satisfy the specific performance needs of operating environments in the European ATM System and based upon the timescales in which their performance contribution is needed in the respective operating environments
Environment	Surroundings in which humans interact with the air, water, landscape, natural resources, flora and fauna. In terms of ATM, ‘the environment’ will be the surroundings in which Air Traffic Management activities are planned or conducted, including research through to development, deployment, and operations.

Term	Definition
Environmental Impact	Any modification of the environment that has or could have an effect on the ecosystem. In this document the main environmental impacts of concern are: • Aircraft noise in the vicinity of an airport, • Airport Local Air Quality (mainly CO, NO_x and Particulate Matter), • Global emissions (mainly CO_2) Fuel burnt is also of concern for the environment because of the direct relationship between fuel burnt and CO_2.
Environmental Impact Assessment (EIA)	The process of identifying and evaluating the environmental impacts of projects as well as proposing mitigations to reduce these impacts on the environment. The assessment scope, as it relates to ATM, considers impacts on the environment that can be affected by aircraft operations or that can affect aircraft operations, e.g. through mitigation rules. The main impacts on the environment related to aircraft movements are caused by emissions resulting from fuel burn and noise produced by the engines and airframe.
EIA plan	The Environmental Impact Assessment plan describes the hypothesis to test, metrics to assess, the tools to use, the required input variables for the tools and methodology used for analysing the results.
EUROCONTROL	European Organisation for the Safety of Air Navigation
SJU Work Programme	The programme which addresses all activities of the SESAR Joint Undertaking Agency.
SESAR Programme	The programme that defines the Research and Development activities and Projects for the SJU.

1.7 Acronyms

Acronym	Definition
3D	3 Dimensional
4D	4 Dimensional
AC	Aircraft
ACI	Airports Council International

Acronym	Definition
ACC	Area Control Centre
AEM	Advanced Emission Model
AGL	Above Ground Level
ALAQS	Airport Local Air Quality Studies
AMAN	Arrival Management
ANP	Aircraft Noise and Performance
APU	Auxiliary Power Unit
ARN	Stockholm Arlanda airport
ASTERIX	All Purpose STructured Eurocontrol SuRveillance Information EXchange
ATAG	Air Transport Action Group
ATCO	Air Traffic Control Officer
ATM	Air Traffic Management
BADA	Base of Aircraft Data
CAEP	Committee on Aviation Environmental Protection
CANSO	Civil Air Navigation Services Organisation
CBA	Cost–Benefit Analysis
CCO	Continuous Climb Operations
CDO	Continuous Descent Operations
CEA	Cost Effectiveness Analysis
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CONOPS	Concept of Operations
CTA	Controlled Time of Arrival
CUA	Cost Utility Analysis
D	Deliverable

Acronym	Definition
dB	Decibel
DEA	Data Envelopment Analysis
DFS	Deutsche Flugsicherung GmbH (German Air Traffic Control)
DP	Deployment Package
DS	Deployment Scenario
DSNA	Direction des Services de la Navigation Aérienne (Directorate of Air Navigation Services, France)
EASA	European Aviation Safety Authority
E-ATMS	European Air Traffic Management System
EC	European Commission
ECAC	European Civil Aviation Conference
ECTL	EUROCONTROL
EEC	EUROCONTROL Experimental Centre
EIA	Environmental Impact Assessment
ENAV	Ente nazionale di assistenza al volo (Italian Government Agency for Air Traffic and Aeronautical Services)
ENV	Environment
E-OCVM	European Operational Concept Validation Methodology
ERM	Environment Reference Material
ESCAPE	EUROCONTROL Simulation Capability and Platform for Experimentation
ETFMS	Enhanced Traffic Flow Management System (EUROCONTROL CFMU)
EU	European Union
FAB	Functional Airspace Block
F2F	Face 2 Face
FDR	Flight Data Recorder
FL	Flight Level
FMS	Flight Management System

Acronym	Definition
FOCA	Federal Office for Civil Aviation
FTS	Fast Time Simulation
GHG	Greenhouse Gas
GIS	Geographical Information System
GPU	Ground Power Unit
GSE	Ground Support Equipment
H_2O	Water
HC	Hydrocarbon
IA	Impact Assessment
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
ILS	Instrument Landing System
IMPACT	EUROCONTROL web portal for the analysis of aircraft noise and emissions
IPR	Intellectual Property Rights.
JU	Joint Undertaking
KPA	Key Performance Area
KPI	Key Performance Indicator
LAQ	Local Air Quality
LCT	Least CO_2 Trajectory
LTO	Landing and Take-off
MCA	Multi Criteria Analysis
MDG	Modelling and Database Group
NATS	National Air Traffic Services (UK)
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium (Dutch National Aerospace Laboratory)
NM	Nautical Miles

Acronym	Definition
NMHC	Non-Methane Hydrocarbons
NOX	Oxides of Nitrogen
OI	Operational Improvement
OSED	Operational Service and Environment Definition
OSL	Oslo airport
P	Project
P&S	Processes and Services
PAR	Performance Assessment Report
PBN	Performance Based Navigation
PEP	Performance Engineer Programme
PM	Particulate Matter
PRU	Performance Review Unit
QNH	Atmospheric pressure at mean sea level
R&D	Research and Development
RNP	Required Navigation Performance
RTA	Required Time of Arrival
RTS	Real Time Simulation
SAS	Scandinavian Airlines
SCBA	Social Cost Benefit Analysis
SEA	Strategic Environmental Assessment
SEL	Sound Exposure Level
SESAR	Single European Sky ATM Research
SICTA	Sistemi Innovativi per il Controllo del Traffico Aereo (Innovative Systems for Air Traffic Control)
SID	Standard Instrument Departure
SJU	SESAR Joint Undertaking (Agency of the European Commission)

Acronym	Definition
SOP	Standard Operating Procedures
SO_X	Oxides of Sulphur
SPR	Safety and Performance Requirements
SSR	Secondary Surveillance Radar
STAR	Standard Terminal Arrival Route
STATFOR	Statistics, Forecasts and Analysis
SWP	Sub Work Package
TA	Transversal Area
TMA	Terminal Manoeuvring Area
TOC	Top of Climb
TOD	Top Of Descent
TOG	Total Organic Gases
UTC	Coordinated Universal Time
VALP	Validation Plan
VALR	Validation Report
VALS	Validation Strategy
VINGA	Validation and Improvement of Next Generation Airspace
VOC	Volatile Organic Compound
V-PAT	Vertical Profile Analysis Tool
WP	Work Package

1.8 Structure of the document

The structure of this document is based around the SESAR environmental impact assessment process presented in section 2.1 - Introduction to the SESAR Environmental impact assessment process which relies on 5 main EIA process steps. Note: these steps should not be confused with SESAR programme steps.

For each EIA process step, the following points are identified:

- What the step is about;
- Who is involved in the step and who is responsible for conducting it;
- What inputs are required at the beginning of the step;
- What outputs should be available at the end of the step;
- Explanation of how the step is taken;
- Checklist with boxes before proceeding;
- List of dos and don'ts.

Finally, appendices provide additional information about:

- Definition of Metrics;
- Environmental impact assessment tools;
- Summary of Guidance on Environmental Interdependencies and Trade-Offs;
- Fuel efficiency assessment based on aircraft derived data from flight trials;
- List with checkboxes.

1.9 Version 4 versus Version 3

The changes made to Version 4 compared to Version 3 concern:

- The SJU template used.
- Some corrections and additions to clarify or facilitate reading.
- Section 2.3.3.4 - Identifying GHG-emission metrics and tools: metrics that are not accessible to all SESAR partners, regardless of IPR issues, have been removed.
- Appendix B - Environmental impact assessment tools: tools that are not accessible to all SESAR partners, regardless of IPR issues, have been removed.

2 Environmental impact assessment process

2.1 Introduction to the SESAR Environmental impact assessment process

Project 16.06.03 has derived its environmental impact assessment process by mapping the ICAO Guidance document (Doc 10031) [1] "Guidance on Environmental Assessment of Proposed Air Traffic Management Operational Changes" to the SESAR validation framework.

As can be seen in Figure 3, which shows the correspondence between the ICAO assessment process (right-hand side) and the one adopted for SESAR (left-hand side), the resulting process is quite generic and straightforward. Results from the environmental impact assessments can also be used to refine the ATM change, making the process cyclic and compatible with the classic Plan-Do-Check-Act approach to validation.

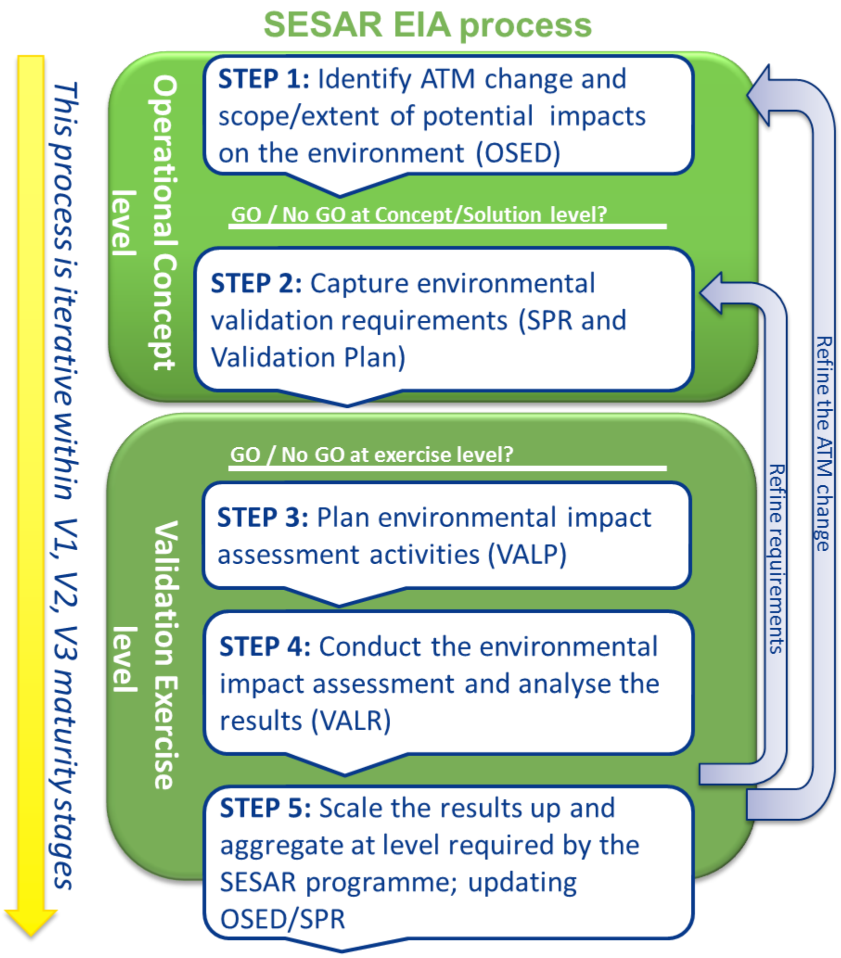


Figure 3: SESAR environmental impact assessment process

This process should enable environmental impact assessment activities to be easily carried out as part of the overall validation process where necessary.

The SESAR EIA process consists of 5 main steps:

- EIA Step 1: Identify ATM change and the scope of potential impacts on the environment;
- EIA Step 2: Define environmental validation requirements;
- EIA Step 3: Plan environmental impact assessment activities;
- EIA Step 4: Conduct the environmental impact assessment exercise;
- EIA Step 5: Scale the results up and aggregate.

The SESAR EIA process encompasses two "Go-No-Go" decisions about carrying out further environmental impact assessments. The first one occurs after EIA Step 1 in order to identify very early on in the process whether it is worth undertaking an environmental impact assessment or whether or not more assessments are required later on in the process. The second one occurs at the Exercise level and allows the decision on conducting a detailed environmental impact assessment to be taken before the writing of the validation plan for that exercise. This decision will be based on criteria determined by the validation exercise management. In any case, every "Go-No-Go" decision should be included in the validation plan.

2.2 Roles

The roles identified in the EIA process are summarised in Table 1. One person can have more than one role.

Table 1: Roles in the SESAR EIA process

Role name	Who	Responsible for
Primary Project Manager	The project manager of a given SESAR solution.	• Coordinating project management and validation activities at a Project level
Exercise Leader	A team member of a SESAR solution Project	• Plan the exercise (VALP) • Responsible for environment data collection and exchange between Primary Projects and Environment Practitioner • Write VALP and VALR
Environment Practitioner	Preferably an expert in EIA although in most cases, with appropriate training, the exercise leader or exercise analysts can fit this role	• Advising which metrics to use (VALP) • Correct application of tools to perform assessment • Conducting the EIA • Generating tables and figures with results • Interpretation of results • Hypothesis testing
Primary Project Manager	The project manager of a given SESAR solution.	• Coordinating project management and validation activities at a Project level

2.3 SESAR Environmental impact assessment process step by step

This section details each of the 5 steps of the SESAR environmental impact assessment process. Each EIA step is broken down into sub-steps showing who is involved in the step, the inputs required at the beginning of the step, the outputs that should be available at the end of the step, an explanation of how the sub-step is performed, a checklist to consult before proceeding and a list of dos and don'ts.

2.3.1 EIA Step 1: Identify ATM change and the scope of potential impacts on the environment

At the first EIA step, the project manager will identify the ATM changes and the scope of potential impacts on the environment with respect to climate change (fuel/CO_2), noise and local air quality.

- **Fuel Efficiency/CO_2**: Fuel efficiency is a pre-cursor to the reduction of exhaust emissions resulting from the combustion of jet fuel from flight movements in all phases of flight. Therefore, variation in fuel burnt is considered a good indicator for evaluating the contribution of aviation to global and local emissions. A good example of this is the direct link between fuel burn and the amount of CO_2 produced (3.15 times the mass of fuel burnt); CO_2 emissions are a major contributor to anthropogenic climate change, therefore their reduction, through improved fuel efficiency, is key to reducing aviation's environmental impact.

- **Noise**: Noise is defined as unwanted sound. Noise impact represents the adverse effect(s) of noise on its recipients (in this case, people living around airports). The noise focus area only covers aircraft noise sources; other noise sources around the airport contributing to the background noise are not considered. This KPA focuses on the quantification of the number of people exposed to aircraft noise, using different types of metric, capturing different aspects of noise impact such as the notion of noise exposure (noise energy perceived on the ground), peaks in noise levels (maximum noise level perceived on the ground), and the frequency of "noisy" events (number of flights/operations exceeding a given noise level threshold during a certain time period).

- **Local Air Quality**: Airport local air quality is a commonly used term to designate the condition of the ambient air to which humans and nature are typically exposed in the vicinity of an airport. In most cases, determining the quality of the air around an airport is based on the estimation of concentration of pollutants. These concentrations are compared with regulations and standards that are established to define acceptable levels of local air quality, including the necessary measures to achieve them. Many issues particular to the local air quality in and around airports are subject to these same regulations. Normally, airport environments comprise a complex mix of emission sources including aircraft, ground support equipment, terminal buildings, and ground vehicular traffic (see ICAO Doc 9889). In the context of SESAR, in most cases only exhaust emissions resulting from jet-fuel consumption can be estimated and only these are considered therefore.

The conclusion of this step will be a "Go-No-Go" decision on whether an environmental assessment will be carried out for this SESAR solution. Determination of the ATM change can be achieved by consulting the supporting documentation. From this consultation, if the ATM change has an obvious environmental impact and-or the environmental scope of the ATM change is clear, it is expected that a "Go" decision will be taken.

If it is unclear whether the ATM change will have an environmental impact or if the scope of the potential impact (i.e. CO_2, noise and-or local air quality) cannot be immediately identified, it may be pertinent to discuss with the Environment Practitioner and carry out an expert judgement process to determine whether the ATM change will or will not have an environmental impact, and the potential environmental scope of any impact identified. If the outcome of the expert judgement process determines that the ATM change will have an impact even though the level of potential impact or the extent (i.e. positive or negative) cannot be estimated, or the environmental scope is still not clear, it is recommended that a “Go” decision will be taken. A “No-Go” decision should be taken only if the results of the scoping and expert judgement processes identify no apparent environmental impact.

The outputs that should be available at the end of the step are a “Go-No Go” decision and the nominated persons for step 2 if a “Go” decision is taken. The table below identifies the responsible roles and the other roles involved in carrying out step 1, the inputs and outputs required, and the sub-steps required for accomplishing the overall objectives of the step.

Sub steps	Responsible Role	Roles Involved	Input	Output
1.1 Understanding the proposed concept and the scenarios for implementation	Project manager	• Environment practitioner	• CONOPS • VALS • State of the art review documents • OSED	• Summary with the purpose of the concept and the scenarios for implementation.
1.2 Assessing any change to the impacts on the environment	Project manager	• Environment practitioner	• Summary with the purpose of the concept and the scenarios for implementation	• 4D trajectory changes for the scenarios for implementation.
1.3 Identifying which environmental impacts should be investigated	Project manager	• Primary Project Manager	• Relevant SESAR environmental impacts as a function of altitude and phase of flight • 4D trajectory changes for the scenarios for implementation	• Environmental impacts that should be investigated
1.4 Identifying environmental performance drivers-targets and environmental benefits	Project manager	• Environment practitioner		• Environmental performance targets
1.5 Taking the “Go-No-Go” decision	Project manager	• Environment practitioner		• “Go-No-Go”: If no change to the environment was identified in Step 1, the environmental impact assessment stops here. A “No-Go” must be justified. • Nomination of focal point for step 2

2.3.1.1 Understanding the proposed concept and the scenarios for implementation

At the beginning of the assessment process, the information about the proposed concept and the scenarios for implementation should be already available in one of the following documents:

- Concept of operations (CONOPS);
- Validation Strategy (VALS);
- State-of-the-art review documents;
- Operational Service and Environment Definition (OSED).

At the first sub step, all roles involved will have to understand the proposed concept and the scenarios for implementation. The findings will be summarized in a review sheet. All roles involved should be able to have collected information about the:

- Concept; a high-level description of the concept;
- Operational improvement SESAR is looking for;
- Phases of flight affected by the new concept.

2.3.1.2 Assessing any change to the impacts on the environment

Based on the information collected in the previous step the Project manager should be able to do a rapid qualitative assessment of any positive or negative change to the impacts on the environment.

Any 4D trajectory change will likely cause a direct change to an aircraft's impacts on the environment and should therefore be investigated.

The main environmental impacts considered for SESAR operational deployments are:

- Impact on the composition of the atmosphere, both globally (mainly CO_2) and locally on air quality;
- Noise which can cause nuisance.

2.3.1.3 Identifying which environmental impacts should be investigated

Guidance on understanding the limits of these impacts is as follows:

- Local air quality (e.g. NO_X, PM, SO_X): 3000ft is considered the conservative upper limit for local air quality impact. However, it is generally accepted that only emissions below 1000ft will impact ground level air quality;
- Noise: 10000ft is considered the conservative upper limit for departures whilst 7000ft is the upper limit for arrivals;
- Fuel burn and CO_2: Fuel burn and CO_2 should be investigated at any level of flight and for any phase of aircraft operation.

Knowing the phase of flight and the flight levels covered by the operational concept, the Project manager will determine which environmental impacts should be investigated. The geographical scale of the applicability of the operational concept will determine which regulations are to be considered. (See also section 2.3.3.8 Identifying Environmental Regulation and Local Constraints when implementing ATM Updates).

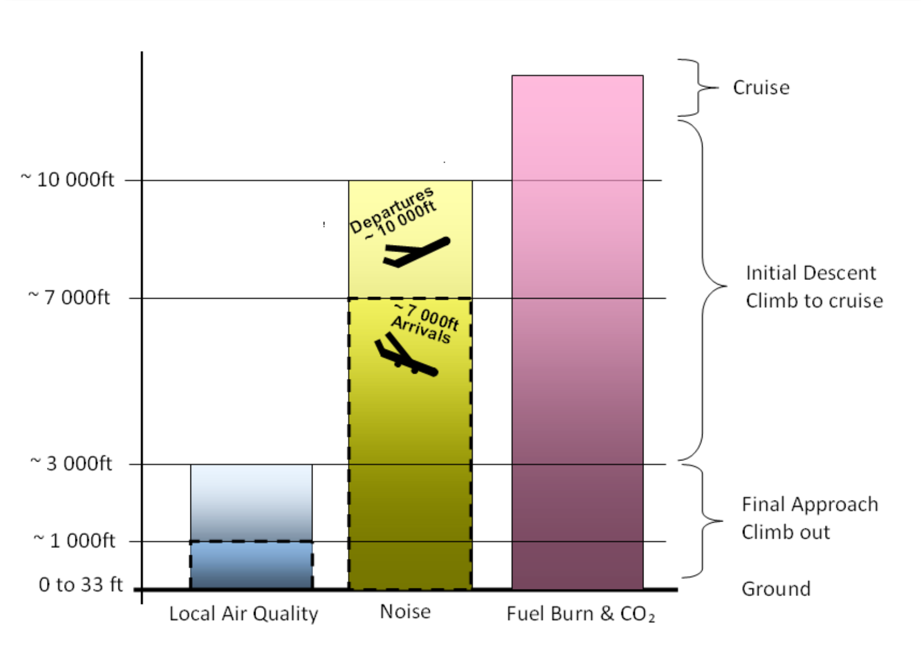


Figure 4: Relevant environmental impacts as a function of altitude and phase of flight

2.3.1.4 Identifying environmental performance drivers-targets and environmental benefits

The project manager leader should capture the environmental performance targets and should also identify the environmental benefits (ENV KPA-KPIs targeted).

2.3.1.5 Taking the "Go-No-Go" decision

By the end of Step 1, the Project manager should have identified whether an SESAR solution should be subject to environmental impact assessments.

2.3.1.6 Dos and don'ts:

- Do ask for support from environmental experts when there are doubts which environmental impacts should be investigated.
- Do justify why no EIA is needed.
- Do decide to assess the environment when no impact is expected but public opinion could have doubts about this in a later deployment.

Checklist	Checkbox
A "Go-No-Go" decision has been taken	
Any "No-Go" decision has been justified.	

2.3.2 EIA Step 2: Define environmental validation requirements

At the beginning of EIA step 2, all involved roles should:

- have a broad understanding of the operational concept to be assessed;
- know if, theoretically or based on previous study results, the concept might be beneficial-detrimental to the environment.

In EIA step 2, the evidence collected in Step 1 is refined. The project manager must determine which validation exercises should require an EIA and take the "Go-No-Go" decision for further environmental impact assessment at an exercise level.

This decision should be based on the validation strategy and a high-level description of each validation exercise.

Sub steps	Responsible Role	Roles Involved	Input	Output
2.1 Developing a detailed understanding of the proposed concept and the alternative scenarios for implementation **2.2** Understanding the validation strategy **2.3** Determining which validation exercises should be subject to an environmental impact assessment and taking the exercise validation "Go-No-Go" decision	Project manager	• Environment practitioner	• Review sheet • Validation Strategy (VALS) • Safety and Performance Requirements (SPR) • List of all validation exercises • Current Operating Methods, new SESAR Operating Method, • Differences between new and current Operating Methods, • Constraining factors to the operational environment • Required new on-board and ground technologies • Required new aircraft performance or navigational capabilities.	• "Go-No-Go" decision for EIA on exercise • Final list of validation exercises requiring an EIA • Nomination of the Environmental Practitioner • Nominated Exercise leader per exercise
2.4 Identifying the contribution of the operational	Project manager	• Focal point • Primary Project Manager	• SPR • Benefits Mechanism model • Exercises requiring an EIA	• Benefit diagram of exercise as part of the SPR if possible

Sub steps	Responsible Role	Roles Involved	Input	Output
projects to environmental benefit expectations and targets				
2-5 Ensuring that requirements for environmental impact assessment are described	Project manager	• Primary Project Manager • Exercise Leader • Focal point • Environmental Practitioner	• SPR	• Recommendations for SPR chapter concerning EIA

2.3.2.1 Developing a detailed understanding of the proposed concept and the alternative scenarios for implementation

The focal point should be able to collect information about:

- Current Operating Methods;
- new SESAR Operating Methods;
- differences between new and current Operating Methods;
- constraining factors to the operational environment:
  - environmentally constrained
  - airspace constrained
  - traffic volume and variation constrained
- required new on-board and ground technologies;
- required new aircraft performance or navigational capabilities.

2.3.2.2 Understanding the validation strategy

The focal point should become familiar with the Validation Strategy and the Safety and Performance Requirements (SPR) documents and ensure that environmental issues are addressed.

The Validation Strategy document should provide:

- a summary of the validation objectives that have to be achieved,
- a synthesis of the overall approach to performance and case assessment, and its link to the relevant operational primary projects validation plan approach,

- the synthesis of the methods, tools and techniques that are going to be used in this validation context providing the rationale for why these specific techniques will be used.

The SPR document should provide the detailed performance requirements to be addressed by the validation exercises.

2.3.2.3 Determining which validation exercises should be subject to an environmental impact assessment and taking the exercise validation “Go-No-Go” decision

The project manager will determine which validation exercises require an EIA and take the “Go-No-Go” decision for further environmental impact assessment at the exercise level. This decision should be based on the validation strategy and a high-level description of each validation exercise. It should be taken in consultation with Primary Project Manager, project manager and planned Exercise leader(s). Note: some validation exercises are not suitable for EIAs. The project manager must justify why no EIA is conducted.

When the final list of validation exercises requiring an EIA is established, the project manager should have continuing contact with the Primary Project Managers and the exercise leaders who will be responsible for carrying out the validation exercises. Together, they should:

- determine the effort required to conduct the EIAs;
- nominate a person, here called Environmental Practitioner, that will be responsible for carrying out the EIAs (EIA Step 3 and EIA Step 4); this person could be either from the Primary Projects or from the environmental support project;
- identify the need for training;
- identify the level of coaching required.

2.3.2.4 Identifying the contribution of the operational projects to environmental benefit expectations and targets

The potential environmental impacts-benefits that could result from the introduction of the concept(s) under evaluation should be identified. To do this, the Benefits Mechanism model (produced by 16.06.06) should be used. It should be noted that most of the time this will be done at the exercise level by the Environmental Practitioner.

2.3.2.5 Ensuring that requirements for environmental impact assessment are described

Based on the information collected so far and their understanding of the concept, the Environmental practitioner should be able to provide recommendations to complete the SPR chapter concerning EIA (if needed). In particular, the Environmental practitioner should try to identify any gaps in the Validation Strategy document and provide recommendations for improving it.

2.3.2.6 Dos and don’ts:

- Do use the same decision criteria as in EIA step 1 for the “Go-No-Go” decision;

- Do use Figure 4: Relevant SESAR environmental impacts as a function of altitude and phase of flight for supporting the “Go-No-Go” decision.

Checklist	Checkbox
The final list of validation exercises requiring an EIA has been produced.	
An Environmental Practitioners has been nominated by the project manager.	
The amount of effort required for the EIA has been determined.	
The need for training has been identified and arranged.	
The level of required coaching has been identified and arranged.	
The expected contribution of the operational projects to the environmental benefits and Targets - objectives has been identified.	
The recommendations for the SPR chapter concerning EIA have been described.	

2.3.3 EIA Step 3: Plan environmental impact assessment activities

At the beginning of step 3, the Exercise Leader, the Environmental Practitioner and the environmental coach - support should already:

- have a very good understanding of the operational concept to be assessed, and understand the reference scenario and the solution scenario including the underlying matching criteria and system boundaries;
- have become familiar with the SESAR Environment Reference Material (i.e. guidance documents, key performance parameters and tools) and should have followed (if necessary) the related environmental training.

The output of step 3, given by the exercise leader, is an EIA plan for the exercises describing the hypotheses to be tested, the metrics and tools to be used, the required input variables for these tools and the methodology used for analysing the results. The EIA plan is part of the VALP.

Sub steps	Responsible Role	Roles Involved	Input	Output
3.1 Understanding the specific operational environment of the validation exercise	Exercise Leader	• Environmental Practitioner • Environmental coach - support	• Environmental validation requirements • Exercise documentation (variable)	• The elements that will influence the environmental impacts • Description of: ○ Current Operating Methods, ○ New SESAR Operating Method, ○ Differences between new and current Operating Methods, ○ Operational constraints (environment,

Sub steps	Responsible Role	Roles Involved	Input	Output
				airspace, traffic volume and variation) • Reference scenario • Solution scenario
3.2 Ensuring assumptions, reference and solution scenarios are compliant with EIA requirements	Exercise Leader	• Environmental Practitioner • Environmental coach - support	• Reference scenario • Solution scenario • Assumptions • EIA requirements as described in this document	• Baseline, reference and solution scenarios compliant with EIA requirements • Assumptions compliant with EIA requirements
3.3 Reassessing which environmental impacts should be investigated and formulating hypotheses about the environmental impacts	Exercise Leader	• Environmental Practitioner • Environmental coach - support	• Scenarios • 4D trajectory changes as a function of altitude and phase of flight	• KPIs to assess • Hypothesis to test environmental impacts
3.4 Identifying GHG-emission metrics and tools	Exercise Leader	• Environmental Practitioner • Environmental coach - support	• KPIs to be assessed • Environmental impact hypothesis to be tested	• Environmental GHG-emission metrics and indicators to be used in the exercise • EIA tools to be used in the exercise
3.5 Identifying airport emissions metrics and tools	Exercise Leader	• Environmental Practitioner • Environmental coach - support	• KPIs to be assessed • Environmental impact hypothesis to be tested	• Environmental Airport emission metrics and indicators to be used in the exercise • EIA tools to be used in the exercise
3.6 Identifying noise metrics and tools	Exercise Leader	• Environmental Practitioner • Environmental coach - support	• KPIs to be assessed • Environmental impact hypothesis to be tested	• Environmental noise metrics and indicators to be used in the exercise • EIA tools to be used in the exercise
3.7 Data requirements for an EIA	Exercise Leader	• Environmental Practitioner • Environmental coach - support	• Environmental noise and emission metrics and indicators to be used in the exercise • EIA tools to be used in the exercise	• EIA plan with: ○ Baseline, reference and solution scenario ○ List with metrics for the assessment ○ Tools to use for the assessment ○ Required input for the tools ○ Methodology for analysing results

Sub steps	Responsible Role	Roles Involved	Input	Output
3.8 Identifying Environmental Regulation and Local Constraints when implementing ATM Updates	Exercise Leader	• Environmental Practitioner • Environmental coach - support	• EIA plan • Overview of regulations with potential implications for EIAs	• List with all relevant environmental regulations

	This step should be repeated for each validation exercise.

2.3.3.1 Understanding the specific operational environment of the validation exercise

Each validation exercise will be conducted in a specific operational environment. Although it is not the responsibility of the Environmental Practitioner to describe this operational environment, he-she has to capture the elements that will influence the environmental impacts.

In Step 3-1, the following elements, which have already been described in generic terms in Step 2, need to be described for the specific operational environment of this particular validation exercise:

- Current Operating Methods;
- New SESAR Operating Method;
- Differences between new and current Operating Methods;
- Constraining factors on the operational environment:
    - environmentally constrained
    - airspace constrained
    - traffic volume and variation constrained

2.3.3.2 Ensuring assumptions, reference and solution scenarios are compliant with EIA requirements

In SESAR, the validation exercises will be one or more of the following types:

- Paper based study, based on expert judgement;
- Fast-time simulation;
- Real-time simulation;
- Live trial (e.g. flight trial).

Within the validation plan for each validation exercise, the Environmental Practitioner will have to:

- Collect all assumptions made about the 4D trajectories;
- Collect all assumptions about traffic growth and movement of aircraft;
- Collect all assumptions about new aircraft capabilities or requirements;
- Collect all assumptions made about the fleet of aircraft composing the traffic samples;
- Collect all assumptions about airspace configuration;
- Collect all assumption about airspace constraints (nature, severity and timing);
- Collect all assumptions made about the meteorological conditions;
- Collect information about the regulations in effect.

ⓘ	These assumptions will be summarised in the validation report as part of Step 4.

ⓘ	In SESAR terminology,
	• the ‘baseline scenario’ refers to the situation at a reference date; e.g. 2005 in SESAR 1 and 2012 in SESAR 2020,
	• ‘reference scenario’ is used for the “do-nothing” situation projected into the future,
	• ‘solution scenarios’ are used for the proposed alternative solutions,
	• ‘relative assessments’ are the results of comparing:
	  ○ the solution scenarios (predicted future levels implementing the proposed solutions), with
	  ○ the reference scenario (predicted future levels just applying the current methods, so no improvements)

	It is very important to understand that relative assessment should be done by comparing the solution scenario with the reference scenarios.
	Wrong: compare the solution scenarios (future with proposed improvements) with the baseline scenario
	Right: compare the solution scenarios (future with proposed improvements) with the reference scenario (future without improvements)

For each validation exercise, the Environmental Practitioner must ensure that:

- The reference and the solution scenarios are comparable e.g.:

- The only difference between the reference and the solution scenarios should concern the elements under evaluation (e.g.: operating methods on the ground or in the air).
- **For real-time and fast-time validation exercises**:
  - The reference scenario should be the current operating methods applied to a representative fleet of aircraft for this specific operational environment. Therefore, the reference scenario corresponds to a future-year "do-nothing" scenario.
  - The solution scenarios should be the new operating methods applied to the same representative fleet of aircraft for this specific operational environment (i.e. same aircraft type - engine type distribution).
  - The traffic volume should be the same for the reference and for the solution scenarios.
  - The traffic volume (and traffic change - growth) is determined by the target date of deployment of the new operating method (i.e. SESAR Step 1, Step 2 and Step 3 deployment target years).
- **For live trial or flight trial**:
  - The reference scenario should be the current operating methods applied to a range of aircraft type-engine types.
  - The solution scenarios should be the new operating methods applied to the same range of aircraft type-engine types (same sample)
  - In the case of a live trial, it is obvious, that the year of operation of the reference and alternative scenarios is always the current year.
  - The part of the trajectories used to compare reference and solution scenarios should be included within the same volume of airspace in order to be able to quantify the impact due to the new operating methods.
  - The entry conditions of flights into the measured airspace should be the same between reference and solution scenarios in terms of traffic complexity.

Fuel efficiency analysis of flight trials

Conducting a fuel efficiency analysis is a challenging but important part of a flight trial. Many factors affect the fuel burn of a flight and often the fuel efficiency difference between the procedures to be assessed is small. Correctly identifying this fuel efficiency difference in the large scatter of factors affecting fuel burn requires that the influencing factors will be handled. A flight burning more fuel than another might actually be the most fuel efficient of the two.

What kind of data the analysis is based on is an important aspect. Aircraft-derived data such as flight recorder data is highly recommendable since this is the only source of information containing the conditions in which the flight was conducted, exactly how the aircraft was flown (both laterally and vertically), how it was configured (flaps, slats, gear, speed brakes etc.) and that contains accurate fuel flow information during all phases of the flight. It is important to keep in mind that the accuracy of the output never can be higher than the accuracy of the input.

Further, it is important to select the appropriate part of the flight for inclusion in the analysis. By excluding parts of the flight not affected by the change to be assessed, many error sources can be removed. At the same time, enough part of the flight needs to be included in order to make sure that all the effects of the change are considered.

The above topics are covered in more detail in Appendix D and concrete tips and guidelines are given on how to conduct a fuel efficiency analysis of a flight trial. Common traps are identified and pointed out. The material is based on the experiences gained and lessons learned by two airspace users (Novair and SAS) from the fuel efficiency analyses that they have themselves conducted in the frame of demonstration activities and fuel efficiency work within the airline.

2.3.3.3 Reassessing which environmental impacts should be investigated and formulating hypotheses about the environmental impacts

The Environmental Practitioner needs to identify the environmental impacts that will be studied. If an environmental impact will not be studied, he-she should explain why. The Exercise Leader must reassess in sub-step 2.3.3.3 what the project manager has assessed in 2.3.2.3. A reassessment is required because additional information could be presented by the Exercise Leader that was not presented by the project manager when the initial assessment was performed. The decision tree is based on the phase of flight, traffic (fleet mix, sample size) and input data.

Table 2: Environmental impact decision tables

Does your operational concept modify the gate-to-gate aircraft trajectories - 2D tracks and-or vertical profiles - or other flight parameters such as engine power settings?	
Yes	Proceed
No	No need to undertake an environmental impact assessment

Which phase of flight does the change in trajectories occur in?	EIAs to be performed		
	Fuel-CO_2	Noise	Airport Emissions
Ground	Yes	No	Yes
Airborne below 3,000ft	Yes	Yes	Yes
3,000ft to 10,000ft	Yes	Yes	No
Above 10,000t	Yes	No	No

Now that the Exercise Leader has identified precisely which environmental impacts might change, he-she needs to formulate the hypotheses. Statistical hypothesis testing requires null and alternative hypothesis for all potential positive (benefits) or negative (impacts) changes that are expected with the implementation of the ATM change. The Exercise Leader and the Environmental Practitioner might need help from a statistician to determine, for example, the minimal required sample sizes and to find the correct statistical methodology for accepting or rejecting a hypothesis. If sample sizes are not large enough for testing, for example, the results cannot be used for hypothesis testing. However, these results could still be useful for improving concepts.

When possible, the Exercise Leader may capture the environmental performance contribution of the project to the overall performance target (scaling of results will be done in EIA Step 5: Scale the results up and aggregate).

2.3.3.4 Identifying GHG-emission metrics and tools

As pointed out under section 1.1, one of the main performance requirements in SESAR is to assess and quantify the environmental benefits of operational concepts in terms of fuel and CO_2 savings. This would allow the SESAR contribution towards the European ATM Master Plan target of 10% fuel saving per flight to be monitored.

In order to help the Environmental Practitioner conduct the necessary assessments, the following metrics for fuel burn and CO_2 emission calculation have been identified and documented. They can be used depending on the type of assessment needed, as well as on the validation exercise constraints. These different metrics can be found in Table 3 as a function of the impact of the OI on fuel and CO_2 that the assessment wants to compute. Available tools that can be used to obtain these metrics are also shown in the table.

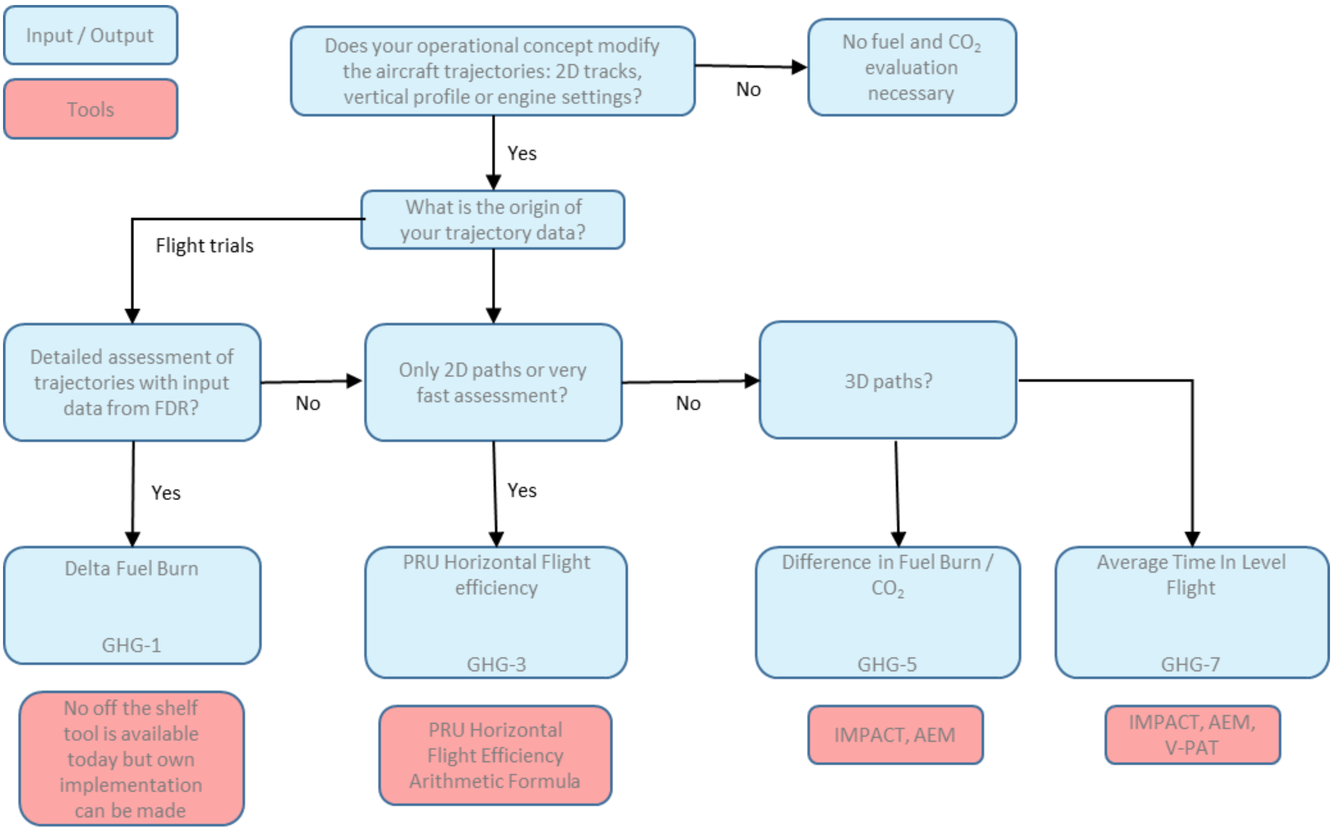
Table 3: GHG-emission metrics

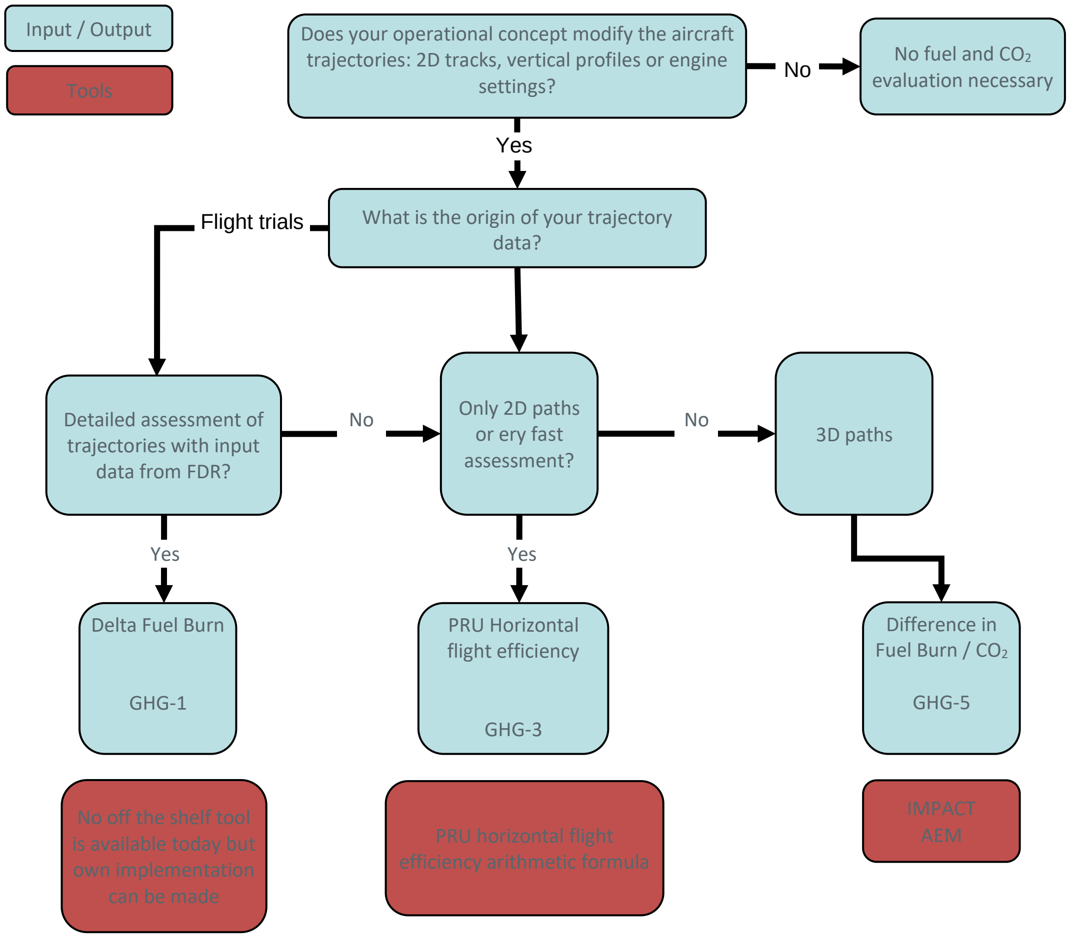
Impact on the local air quality	Metric description	Id	Tools
What is the relative difference in fuel burn or CO_2 between two groups of flights compared to the theoretical optimum?	**Delta Fuel Burn and-or CO_2 (kg)**	GHG-1	No off-the-shelf tool is available today but an individual airspace-user tool can be implemented
What is the route-length penalty (directly related to fuel burn at constant en-route thrust) imposed by ATM on a flight?	**PRU Horizontal Flight-Efficiency Metric (%)**	GHG-3	Application of PRU horizontal flight efficiency arithmetic formula
What is the relative difference in fuel burn or CO_2 between two groups of flights?	**Difference in fuel burn and-or CO_2 (kg)**	GHG-5	IMPACT, AEM
What is the relative difference in fuel burn or CO_2 between two groups of flights considering their 3D path only?	**Difference in fuel and-or CO_2 (kg)**	GHG-6	IMPACT, AEM
What is the average time flown level on intermediate inefficient level segments in the descent phase (from Top of Descent)	**Average time in level flight (seconds)**	GHG-7	IMPACT, AEM, V-PAT

The PRU horizontal flight efficiency metric considers the ratio of a horizontal distance (2D flight path) between 40 NM from the departure and destination aerodromes to the great circle distance to be used as a proxy for fuel burn overhead. Distance flown is a parameter that is quite easily compared and is suitable for validation.

The Delta Fuel Burn metric is used for flight trials when Flight Recorder Data (FDR) is available. Today, there is no off the shelf system that implements the Delta Burn metric but it can quite easily be implemented by the airline itself. Novair and SAS both use such methods. However, implementation requires the use of the aircraft-manufacturer performance tools, which are generally only made available to Airspace Users.

Figure 5: Decision tree to determine the Fuel and CO_2 metrics to be used





Conversion factor to be used to convert the masses of jet fuel burned into masses of CO_2 emissions

The CAEP Secretariat recommends that the GMTF (and CAEP more broadly) use a conversion factor of 3.16 g CO_2 per g of Jet-A, reconfirming a previous recommendation from WG3. In addition, should it be needed, the group also recommended a factor of 3.10 g CO_2 per g of AvGas or Jet-B. Thus, it is recommended that these fuel to CO_2 emissions factors be used in the MRV system to support a GMBM for international aviation. The 3.16 value can be found in the Doc 9889 ICAO 1st edition 2011 and others.

However, in Europe, as early as 2009, with the Commission Decision 339/EC[6] the emission factor 3.15 was indicated for the mass conversion from Jet-A to CO2. Now, even the latest **COMMISSION IMPLEMENTING REGULATION (EU) 2018/2066 of 19 December 2018**[7] (on the monitoring and reporting of greenhouse gas emissions, and which integrates CORSIA to ETS,

[6] COMMISSION DECISION of 16 April 2009 amending Decision 2007/589/EC as regards the inclusion of monitoring and reporting guidelines for emissions and tonne-kilometre data from aviation activities.

[7] COMMISSION IMPLEMENTING REGULATION (EU) 2018/2066 of 19 December 2018 on the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council and amending Commission Regulation (EU) No 601/2012.

	applicable since 1 January 2019, for the period after January 2021) recommends, FOR THE MOMENT, that 3.15 factor for Jet-A fuel is still to be used for ETS and also for CORSIA in Europe! In the context of SESAR, historically, we use 3.15 because it allows comparison with the EU ETS. EUROCONTROL uses 3.15 because it allows comparison with the EU ETS and the EUROCONTROL European Emissions Inventory System. In the European Aviation Environment Report the value used is 3.16 to align with ICAO. Note that the exact value originally used by ICAO was 3.157. The value 3.149 has been used in an older version of the EUROCONTROL standard input for EUROCONTROL cost-benefit analyses, BUT NOW, and for some years now it has been 3.15. **In view of the above, emission factor 3.15 should continue to be used in SESAR 2020**, for the sake of internal consistency within the programme and at least unless the EU ETS decides to move to 3.16. Nevertheless, factor 3.16 should be used when the evaluation concerns comparisons with studies carried out within the ICAO framework or using the factor recommended by ICAO, to ensure external consistency.

2.3.3.5 Identifying airport emissions metrics and tools

Although no performance targets are defined in SESAR for non-CO_2 emissions, it is recognised that there is a range of activities linked to aviation, especially at the airport level, which generate emissions and that could have an impact on local air quality (LAQ) concentrations. In order to assess the impact of SESAR operational concepts on airport-related emissions it could be sufficient to make an inventory of the mass of pollutants emitted by the relevant airport emissions sources.

The most relevant airport-related emissions include:

- NOx: Nitrogen oxides, including nitrogen dioxide (NO_2) and nitrogen oxide (NO);
- VOC: Volatile organic compounds (including non-methane hydrocarbons (NMHC));
- CO: Carbon monoxide;
- PM: Particulate matter (fraction size PM2.5 and PM10);
- SOx: Sulphur oxides.

Typical airport emission sources used for developing emissions inventories include aircraft and non-aircraft sources, classified according to the four groups summarised in Table 4:

Table 4: Airport emissions sources

Aircraft	Ground Equipment	Infrastructure	Access traffic-parking
a) Aircraft main engines b) APU c) Brakes and tyres	a) Ground Power Units (GPU) b) Ground Support Equipment (GSE)	a) Power plants b) Kerosene storage and distribution c) Fire training d) Surface snow removal, de-icing	a) Access traffic for passengers, workers, freight b) Car park emissions

Aircraft	Ground Equipment	Infrastructure	Access traffic-parking
	c) Airside vehicles (service vehicles, passenger buses) d) Aircraft de-icing	e) Aircraft & vehicle maintenance f) Airport building construction, maintenance and cleaning	

Seven metrics have been identified to cover the basic requirements of airport emission analysis in the context of SESAR. These metrics range from single-event indicators, which look into emissions from a single LTO cycle, to integrated indicators that can scale results to the ECAC level. One indicator looks at non-aircraft emissions. The different metrics can be found in Table 5 as a function of the impact of the OI on local air quality that the assessment wants to compute.

Table 5: Airport emissions metrics

Impact on the local air quality	Metric description	Id	Tools
What is the impact on the fuel and emissions produced by aircraft within the LTO cycle as a result of ATM changes?	**Fuel and Emissions per LTO Movement**	APTEMS-01	IMPACT Open-ALAQS
What is the change in emissions produced at an airport as a result of ATM changes?	**Delta Spatial distribution of emissions - Airborne LTO**	APTEMS-02	IMPACT Open-ALAQS
What is the temporal difference in emissions produced by aircraft within the LTO cycle as a result of ATM changes?	**Delta Temporal distribution of emissions - Airborne LTO**	APTEMS-03	IMPACT Open-ALAQS
What is the difference in fuel and emissions produced by aircraft while taxiing as a result of ATM changes?	**Delta Taxi Fuel and Emissions per movement**	APTEMS-04	IMPACT Open-ALAQS
What is the ECAC-level impact on the fuel and emissions produced by taxiing aircraft as a result of ATM changes?	**Delta Taxi Fuel scaled to ECAC level**	APTEMS-05	IMPACT Open-ALAQS
What is the impact on the fuel and emissions produced by aircraft within the LTO cycle at the destination airport as a result of ATM changes affecting the departure airport?	**Delta LTO Fuel -knock on impact to destination airport**	APTEMS-06	IMPACT Open-ALAQS
What is the impact on emissions produced by non-aircraft sources as a result of ATM changes?	**Delta Non-Aircraft Emissions**	APTEMS-07	Open-ALAQS

Other advanced airport emission metrics have been identified but their calculation is subject to expert judgement and they are not included in this document.

ⓘ	It is not in the scope of SESAR to account for non-aircraft sources when performing environmental assessments. Non-aircraft sources should be evaluated on a case-by-case basis and only when full assessment is required (e.g. when assessing the implementation of an OI at a particular airport).

The steps involved in deciding which airport emission metrics should be used for each specific situation, based on the size of the traffic sample, where trajectories are affected by the OI being investigated and so on are as follows:

- Determine whether an airport emissions assessment is required based on the altitude at which the operational concept reflects a change in the aircraft trajectories. The reference LTO cycle for an aircraft is usually found below 3,000ft AGL. This cycle consists of four modal phases to represent approach, taxi-idle, take-off and climb. The LTO cycle is intended to address aircraft operations below the atmospheric mixing height or inversion layer, which, on average, extends to a height of approximately 3,000ft. Pollutants emitted below the mixing height can have an impact on local air quality (LAQ). If the operational concept only influences flight phases above 3,000ft, it is not likely to have an effect on LAQ; therefore an airport emissions assessment is not required in this case.

- If an assessment is required, the following step is to check how many movements are affected. If only a limited number of flight movements are affected or if data is available for a small number of movements, APTEMS-01 may be used. This will provide basic information about airport emissions within the LTO cycle that could be sufficient in most cases.

What is the size of the traffic sample?	Which metric to calculate?
A few flights	APTEMS-01
Many flights (a representative traffic sample, i.e. over several hours)	APTEMS-01 APTEMS-02 APTEMS-03 APTEMS-04 APTEMS-05 APTEMS-06 APTEMS-07

- Depending on the altitude that the operational concept has an effect in, the next step is to determine whether the flight segment(s) to be assessed is (are) at ground level (below 1,000ft) or airborne (1,000-3,000ft) within the LTO cycle. For 'ground' segments, it should be decided whether aircraft and-or non-aircraft emission sources are considered in the assessment.

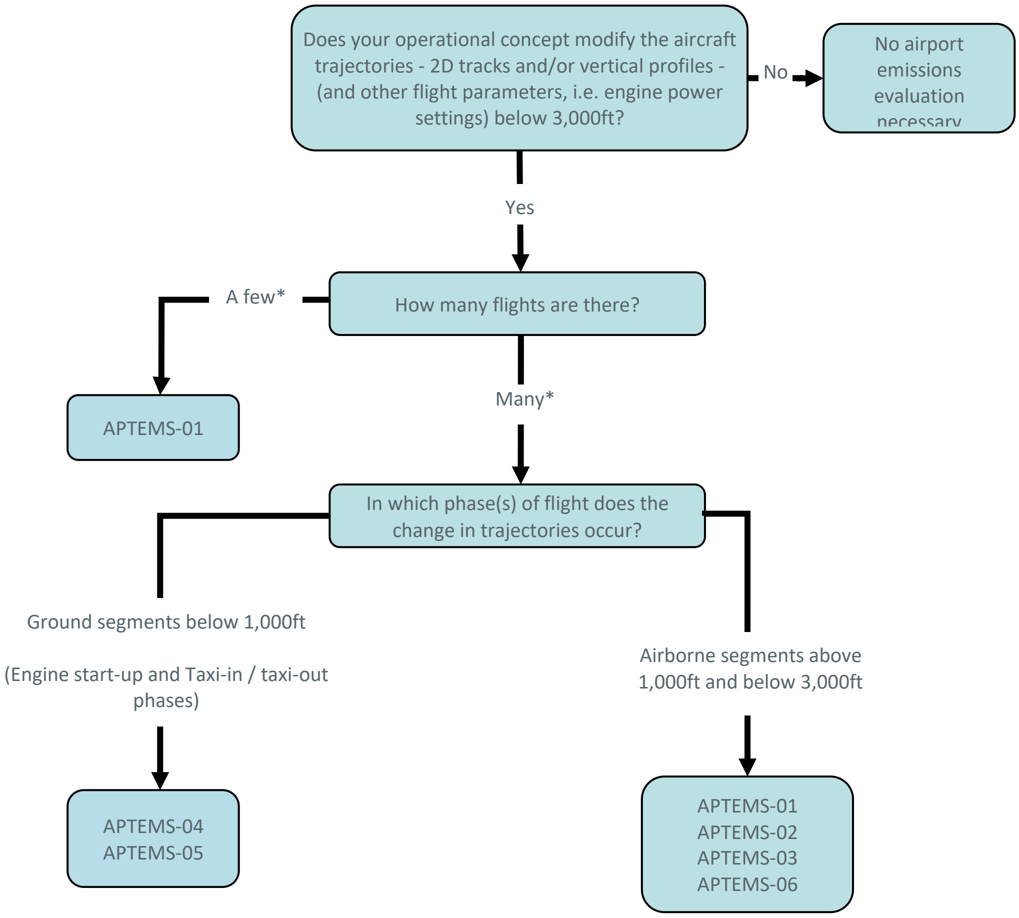
	Which metric to calculate?	
At which altitude are aircraft trajectories modified?	Aircraft emissions sources	Non-aircraft emissions sources
Below 1,000ft (engine start-up and taxi-in - taxi-out phases)	APTEMS-04 APTEMS-05	APTEMS-07
Between 1,000-3,000ft	APTEMS-01 APTEMS-02 APTEMS-03 APTEMS-06	N-A
Above 3,000ft	N-A (Apply fuel and CO_2 metrics)	N-A

This decision tree is shown visually in Figure 6.

**It is up to the environmental practitioner to decide whether a few flights or many flights are being analysed.*

ⓘ	Airport emissions assessments are not required for all SESAR operational concepts. The Exercise Leader should call for assistance on airport-related emission metrics and tools, on a case-by-case basis.

Figure 6: Decision tree to determine the emission metrics to be used as a function of operational modification



2.3.3.6 Identifying noise metrics and tools

As mentioned under section 1.1, Noise assessment should also be included in the environmental impact assessment. This section provides a methodology for determining the kind of noise assessment to be performed.

Eight noise metrics have been identified to assess the noise impact. These metrics are clearly mature and all can be calculated with the IMPACT noise model. Five of them are based on size-area of the noise contours whereas others consider the number of people living inside those contours. Six of the metrics (three area metrics and their associated population metrics) deal with aggregate noise levels, the remaining two area metrics deal with noise levels from a given single aircraft event.

A complete list of metrics can be found in Table 6 as a function of the OI noise exposure impact the assessment is intended to compute. Others metrics have been proposed in the SESAR 16.06.03 D69 Deliverable, but these later metrics have no proven record and should only be used with care in a noise assessment.

Table 6: List of noise metrics as a function of the impact of the OI on noise exposure

Impact on noise exposure	Metric description	Id	Tools
What is the change in the **size of the area** where people will be **moderately exposed** to aircraft noise, as a result of ATM changes? (**Many flights** are concerned)	**Delta Area (%) of the L_{DEN}50dB(A) contour**	Noise-01	IMPACT
What is the change in the **size of the area** where people will be **highly exposed** to aircraft noise, as a result of ATM changes? (**Many flights** are concerned) *(This metrics is only available at high-noise airports)*	**Delta Area (%) of the L_{DEN}65dB(A) contour**	Noise-02	IMPACT
What is the change in the **size of the area** where people will be **moderately exposed** to a **single aircraft event** noise, as a result of ATM changes?	**Delta Area (%) of the SEL 70dB(A) contour**	Noise-03	IMPACT
What is the change in the **size of the area** where people will be **highly exposed** to **a single aircraft event** noise, as a result of ATM changes? (*This metrics is only available for high-noise flights)*	**Delta Area (%) of the SEL 85dB(A) contour**	Noise-04	IMPACT
What is the change in the **number of people moderately exposed** to aircraft noise, as a result of ATM changes? (**Many flights** are concerned)	**Delta Number of people (%) living inside the L_{DEN} 50dB(A) contour**	Noise-05	IMPACT
How many **people** are **highly exposed** to aircraft noise, as a result of ATM changes? (**Many flights** are concerned) (*This metrics is only available at high-noise airports.)*	**Number of people inside L_{DEN} 65dB(A) contour**	Noise-06	IMPACT
What is the change in the **size of the zone** inside which more than **N flight** events (over a given time period) exceed $L_A$max 70 dB(A), as a result of ATM changes	**Delta Area (%) of the NA70 contour for a given number of events N, determined on the basis of each specific case (e.g. 10, 20, 50 or 100)**	Noise-07	IMPACT
What is the change in the **number of people** experiencing more than **N flight** events (over a given time period), which exceed $L_A$max 70 dB(A), as a result of ATM changes.	**Delta number of people (%) inside the NA70 contours as described above**	Noise-08	IMPACT

The steps undertaken to decide which of the dedicated noise metrics should be used for each specific situation, based on where trajectories are affected by the OI being investigated, the affected traffic and on the availability of information on flight times are as follows:

- Determine whether a noise assessment is required, based on the altitude at which an OI leads to a change in trajectories. If it only has an effect above 7,000ft on arrival or 10,000ft on departure this will not result in a change in the noise received on the ground, so a noise assessment is not required in this case.

Does your operational concept modify the aircraft trajectories - 2D tracks and-or vertical profiles - or other flight parameters such as engine power settings below 7,000ft on arrival or 10,000ft on departure?	
Yes	Proceed
No	No need to undertake a noise impact assessment

- If an assessment is required, the following step is to check how many movements are affected. If only a limited number of flight movements are affected or if data is only available for a small number of movements, the single-event metrics NOISE-03 and NOISE-04 should be used. If many flight movements are affected, the noise information required must be determined: either the change in the size of the area where people will be exposed to aircraft noise due to the OI (choose Aggregate noise) or the change in the number of people who will be exposed to aircraft noise due to the OI (choose Population counts).

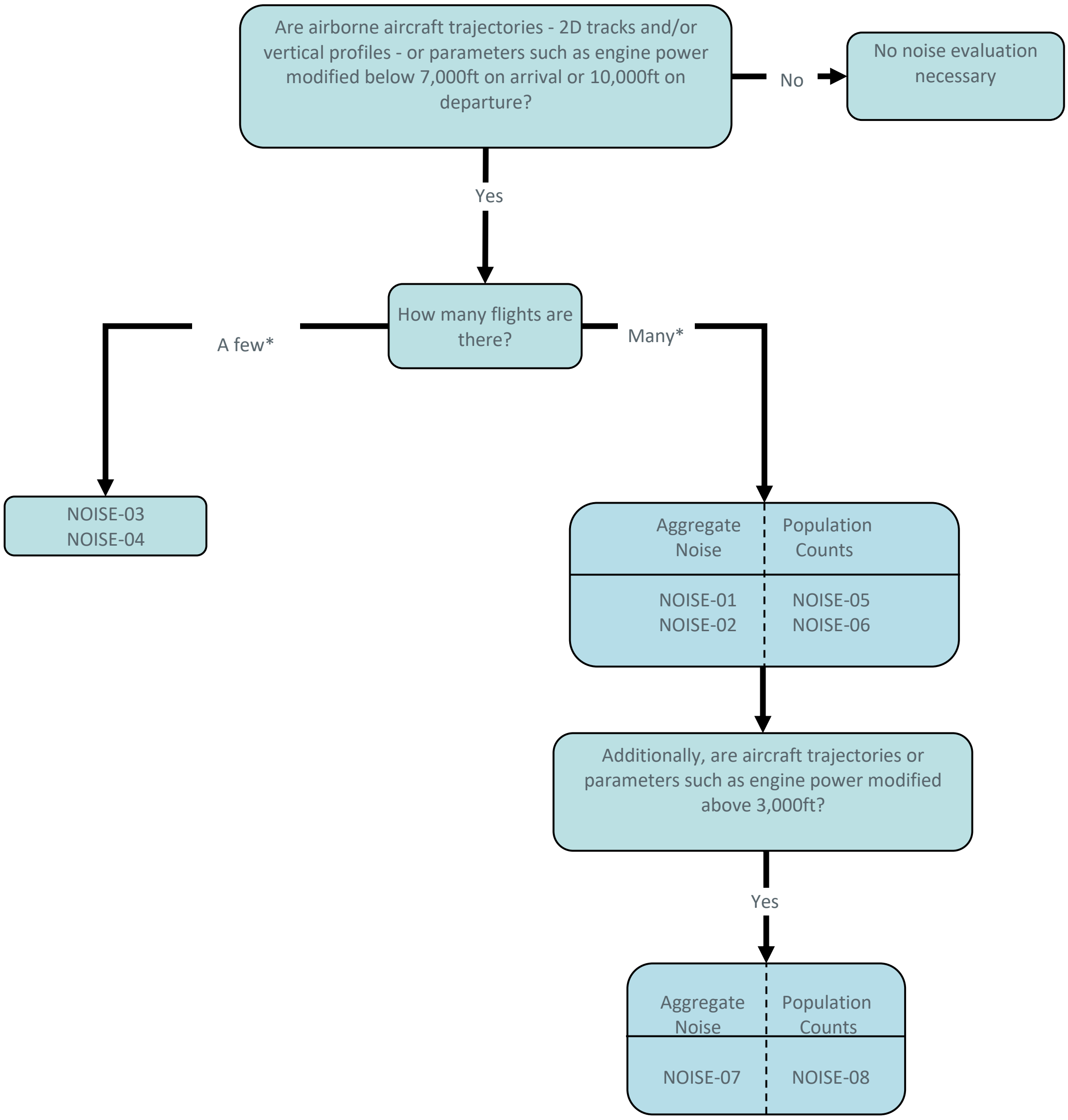
	What noise information is to be determined?	
What is the size of the traffic sample?	**Noise contour area**	**The number of people impacted**
A few flights	NOISE-03 + NOISE-04	No
Many flights (a representative traffic sample over several hours)	Aggregate noise	Population counts

- If a noise assessment is required, if many flights are affected and if the noise information required has been determined, the following step is to check whether aircraft trajectories are modified above 3,000ft. The dedicated noise metrics will be determined as a function of the answer to this question and the noise information required

	What noise information is required?	
Are aircraft trajectories modified above 3,000ft?	**Aggregate noise**	**Population counts**
Yes	NOISE-01 + NOISE-02 + NOISE-07	NOISE-05 + NOISE-06 + NOISE-08
No	NOISE-01 + NOISE-02	NOISE-05 + NOISE-06

This decision tree is shown visually in Figure 7.

Figure 7: Decision tree to determine the dedicated noise metrics as a function of operational modification



2.3.3.7 Data requirements for an EIA

Data requirements for environmental impact assessments are determined by the analysis tool that will be used to perform the assessment. In the case of most of the assessments that will be performed in SESAR, this tool will be IMPACT.

The complete description of input data requirements for IMPACT is given in the Input File Documentation in the Support section of the tool and is not repeated here since it will be maintained on the IMPACT site before any changes are migrated into this document.

Different types of input data (files) can be used. These are listed below:

- Static data
  - Airports
  - Runways
- Traffic movement data
  - Operations
- Trajectory-related data
  - 2D-Tracks
  - Vector-Tracks
  - Fixed-point vertical profiles
  - Approach procedural steps
  - Departure procedural steps
  - 4D-trajectories

The Operations data constitute the central piece of information used by IMPACT to link and aggregate the different types of input data listed above, in order to create the IMPACT Common Input Data (CID), which is further exported to the noise and-or the emissions modules to perform the noise and-or emissions calculations.

The Operations data provides the list of operations – or groups of operations – for a given scenario, with the following (non-exhaustive) list of information for each:

- Aircraft type;
- Operation type (arrival or departure);
- Route (2D-Track - Vector-Track) or full trajectory (4D-trajectory) used ;
- Runway used;
- Number of operations (1 in the case of a single operation – greater than 1 in the case of groups of operations).

It is important to note that not all of the above-mentioned data need to be supplied for performing analyses. As explained above, the “Operations” are strictly required. The provision or not of the other types of data depends on the nature of the environmental assessments to be performed and the source input information which is available. The main rules are detailed below.

Static Data

Even on large-scale studies, the calculation of global (including en-route emissions) requires the provision of Airports information (airport reference point coordinates are required to build the complete aircraft trajectories from the departure airport to the arrival one). For airport noise and emissions calculations, Runways data is also mandatory.

Trajectory-related data

If radar-like data or plotted 4D-simulator data are available, the definition of the aircraft trajectory can be directly provided in the form of “4D-trajectories”, provided that this input information includes engine thrust data (for noise assessments) and-or fuel burn data (for emissions assessments) as well. If such thrust and-or fuel information is missing, it is recommended to only use the geographic (X,Y or Lat-Long) component of the radar or simulated 4D trajectories, and replace the vertical portion with vertical fixed-point profiles or approach-departure procedural steps data. For a more theoretical analysis, input data is more likely to be defined in the form of “2D-tracks” or “Vector Tracks”, combined with either “vertical fixed-point profiles” or “approach-departure procedural steps” data. The Approach procedural steps and Departure procedural steps formalism is used to model approach and departure procedures in the vicinity of airports.

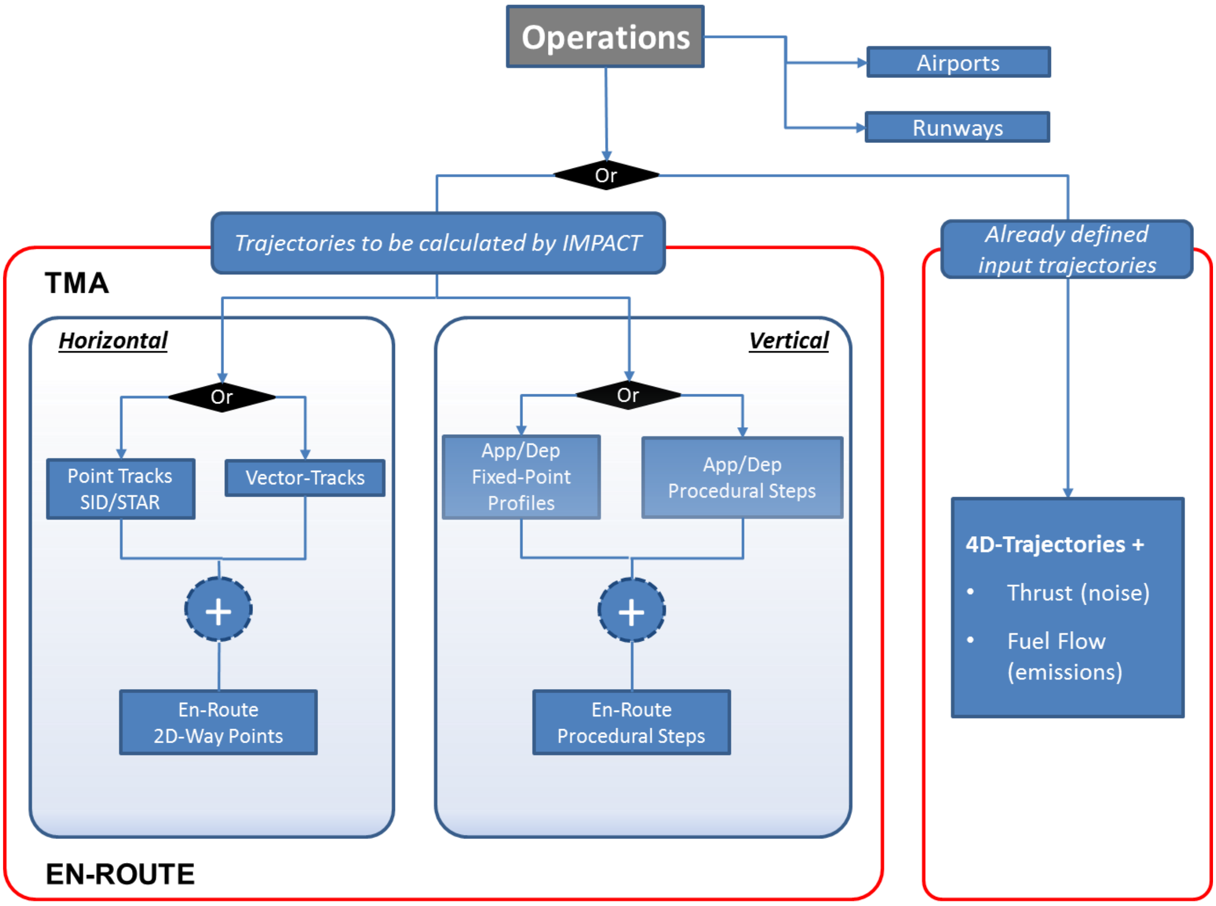


Figure 8: IMPACT data merging process to build aircraft trajectories

Other analysis systems than IMPACT have their own input data requirements that will be described in their appropriate documentation. The Environmental Practitioner should check with this documentation early on in the analysis process if it will be required to use metrics that require these tools.

	It is recommended checking the compatibility of the input data and their validity during a pre-acceptance test of the validation platform.

2.3.3.8 Identifying Environmental Regulation and Local Constraints when implementing ATM Updates

Aviation's environmental impact is regulated through both aviation-specific legislative instruments and through more general environmental regulations, policies and rules which are applicable to industry or society in general but also have relevance for aviation. Therefore there may be local, national or international legislation regulating the operational environment where the operational changes care proposed to be implemented. This is often the case for projects related to airport and TMA operations where both European noise and local air quality legislation and local measures can be applicable. It is vital therefore to identify and take account of all relevant environmental legislation.

For example, the 2002-49-EC Environmental Noise Directive covers the assessment and management of environmental noise. It covers airports with more than 50,000 movements and requires the relevant competent authority to agree and publish a noise action plan. SESAR Solutions that might increase or shift the noise impact at an airport may hinder the airport in meeting its agreed plan. Therefore, it is important to engage with the airport if a SESAR Solution is expected to have such an impact, or the EIA identifies that this is the case.

Many locations are also subject to specific local measures and it is essential to engage with local stakeholders to identify any that are applicable. For example, some airports are subject to noise limits with measurements taken at specific points. Single movements which exceed the maximum authorized noise level for a given ground location are penalised. The main influences on the noise levels measured are altitude, thrust, lateral proximity, aircraft type and weather. Theoretically, SESAR Solutions could affect the first three factors and may lead to operators being penalised if this is not taken into consideration during implementation.

As well as adhering to relevant legislation, local community acceptance may be a constraint to the implementation of operational changes. For communities in the vicinity of airports, aircraft noise has been a local issue for a long time. In recent years, however, aircraft noise has become an issue in communities that are more and more distant (often 20 to 30 km) from airports. Consequently, aircraft noise has become a constant constraint to both growth and efficiency improvements to such an extent that communities will no longer accept major changes to procedures if they do not gain either an actual or a perceived reduction in noise. Although such opposition to change from communities, in the absence of a reduction in noise, can be overcome if there are good safety or security arguments for making a change, to date the saving of fuel alone has not been considered as sufficient benefit to communities to overcome their opposition. In the absence of government policies for managing noise in the context of improved efficiency, noise issues will continue to be a constraint on capacity, and ANSPs will not be able to fully optimise improvements in efficiency.

At a local level, there may also be interdependencies between these environmental impacts such that the reduction of one environmental impact may come at the cost of another (See section 2.3.4.5).

This may be particularly significant where noise and CO_2 have to be traded as the immediacy and tangibility of noise impacts have led to a strong public focus on that issue, which can jeopardise the delivery of CO_2 benefits from the new concept to be deployed.

A possible limitation of the EIA process is that whilst it is particularly good at capturing the local impacts of a particular airspace change and the subsequent community response, the results of the EIA may be non-transferrable or scalable due to the variability of local factors. For example, an EIA completed at one particular airport may indicate significant benefits to fuel burn reduction for airlines, whilst at the same time, due to local factors, result in significant fuel burn penalties at another.

This document presents a common approach for performing Environmental Impact Assessments (EIAs) (See 2.3.5). This common approach is essential to ensure the compatibility of the different assessments, thus ensuring that the overall environmental impact of deployments can be estimated. Caution should be used when scaling EIA results to, for instance, ECAC level as local factors may in many cases limit such standardisation and aggregation.

Table 7 provides an overview of the main current environmental regulations applying at global, European, national, and local level. More detailed information about Regulatory aspects can be found in Project 16.03.07 – D02 – Base-level regulatory review, Project 16.03.07 – D06 – Analysis of Environmental Regulatory Requirements, and Project 16.06.03 – D72 – Second Regulatory Update.

Table 7: Overview [8] of regulations with potential implications for EIAs (Source: SJU, Base Level Regulatory Review, 14 February 2012)

Geographical scale	Impacts	Regulations	Applicability
Global	**All**	Aarhus Convention	EIA may be required to support requests for public consultation on proposed airspace changes.
Europe	**All**	Strategic Environmental Assessment (SEA) Directive 2001-42-EC	If a SEA is triggered during SESAR deployment, analysis of alternatives must be demonstrated (including a "do nothing" scenario).
		Single European Sky (SES) legislation packages	The EIA should identify and account for environmental implications according to the specific guidance and performance aspects of individual SES areas (e.g. shortening of route lengths)
		Performance Regulation (EC 691-2010) (Performance Review Scheme) and 390-2013 (Performance Scheme Implementing Rule)	The environmental support project should ensure that performance assessment methods and metrics used in SESAR are consistent (where relevant) with the Performance Review Scheme. Identify where potential SESAR solutions can contribute to achieving Performance Scheme targets.
		716/2014/EC Implementing Regulation on the establishment of the Pilot Common Project (PCP)	The Regulation supports the deployment of key functionalities expected to bring major performance and cost benefits for the European aviation network.

[8] This table is non-exhaustive and the relevant checks should be made for each individual EIA.

Geographical scale	Impacts	Regulations	Applicability
	Noise	Directive 2002-49-EC on Environmental Noise	EIA may be required to support agreed airport noise impact plans or requests for consultation or to demonstrate that proposed SESAR Solutions will not increase or redistribute noise impact.
		Regulation 598-2014 on noise-related operating restrictions.	Provide data to influence the choice of appropriate measures to reduce aircraft noise in the context of the ICAO Balanced Approach. Increased emphasis on transparent assessment before the adoption of sub-optimal procedures.
	LAQ	EC air quality directive	Provide data to support air quality plans.
		EC national emissions ceiling directive	Ensure impacts are quantified as reliably as possible, especially to support the preparation and update of realistic (performance driven) national emission inventories and projections with regard to the pollutants covered under the Directive.
National or Local	Noise	Multiple – triggered if SESAR Solution increases or shifts noise impact	EIA may be required to support agreed airport noise impact plans or requests for consultation or to demonstrate that proposed SESAR Solutions will not increase or redistribute noise impact
Local	Noise	Noise abatement procedures-routes that could significantly change local noise climate	EIA should indicate when SESAR Solutions may lead to significant changes in noise impacts.
		Noise limits (at specific measurement points)	Consider that changes in altitude, thrust, and lateral proximity can affect noise measurement and identify where potential SESAR Solutions may impact these factors at noise measurement points.

2.3.3.9 Dos and don’ts:

- Keep in mind that the noise metrics are purely based on acoustic levels and are only representative of noise exposure level (and are not representative of noise annoyance);
- Remember that two noise exposure levels (moderate and high) can be computed at each output of the noise metrics decision tree;
- Don’t compare results from two different metrics;
- Do check which local, national and international regulation-legislation could be applicable to an OI;
- Do carry out (in conjunction with local stakeholders) an assessment of how the proposed measure will impact compliance with locally applicable legislation;
- Base the analysis on the most accurate data source available (preferably flight recorder data);
- Make sure to handle any anomalies in the flight recorder data in order for these not to erroneously affect the results;
- Choose the reference and trial flight datasets with care. The more similar the two datasets are the fewer factors might need to be compensated for in order to identify the fuel efficiency difference correlated to the change to be assessed;
- Include as many flights as possible in the reference and trial datasets;

- Preferably set up the trial and choose the datasets so that only one operational improvement at a time is assessed (and differs between the two datasets);
- Beware of trial flights being treated as “royal flights”;
- Handle as many of the parameters affecting the fuel consumption of the flights as possible before comparing fuel burn (either through using the delta burn method or by normalising using mathematical formulas);
- Ensure that the behaviour of the participating airlines is comparable and also ensure that the individual airline behaviour is the same for both the reference and trial flights. If not, this needs to be corrected for;
- Determine the emissions species to be considered. Not all air pollutants are relevant or needed for emission inventories. Regulatory requirements should be consulted to determine which emission species are actually necessary to the inventory;
- Determine the relevant emission sources and quantify the emissions from those sources. Many different emission sources can be found at airports. However, depending on the objectives of the validation exercise, not all types of emission source are relevant for the assessment;
- Determine the system perimeter and consider macro scale issues (regional emissions inventories) to the extent relevant. Note that an airport is always part of a wider environment that goes beyond the perimeter fence and property line of the airfield. For certain purposes, such as modelling of O_3 formation, emissions of a larger regional perimeter (e.g. an air shed) may be developed;
- Use airport-specific data whenever possible (i.e. use of the real taxiing time for each movement). Airport schedules vary, resulting in the time periods in which the emissions actually occur being different. This results in data collection being required for each individual airport, although simplified procedures and assumptions can be used in some cases;
- Implement quality assurance and control measures (to characterise uncertainties and limitations of the data). In order to achieve reliable results, emission inventories should go through a quality control process;
- Check for availability of airport-specific emission factors for non-aircraft sources. If these are not available, please ask the environmental support project. One of the main problems facing those who wish to complete local air quality studies for airports is that there is no harmonised emission factor database for all airport pollution sources;
- Use the real engine fit for every aircraft. This is possible with the unique registration number attributed to each aircraft. Emissions from an aircraft-engine combination are mainly a function of three parameters: time-in-mode (TIM), engine emission indices (EI) and engine fuel flow. If there is only one engine type allocated per aircraft type, this can lead to large errors in emissions because emissions factors vary widely from one engine type to another and two aircraft of the same type can have different engine combinations;

- Report emissions for the same pollutants in the same units, in order to allow comparisons among different scenarios. GHG emissions are typically reported in metric tonnes. However, depending on the units of the source data (e.g., emission factors), emissions calculations can directly result in either English (e.g., lbs, ft) or metric (e.g., kg, m) units. These should all be converted to a common unit, preferably the metric tonne. Using this common unit allows easy review and comparisons with other inventories.

Checklist	Checkbox
The elements that will influence the environmental impacts are known.	
The differences between new and current operating methods are known.	
The baseline scenarios, the reference scenarios and solution scenarios are compliant with EIA requirements.	
The assumptions are compliant with EIA requirements.	
The hypotheses for testing the environmental impacts have been defined.	
The GHG-emission metrics and tools have been determined.	
The Airport emission metrics and tools have been determined.	
The Noise metrics and tools have been determined.	
The required data is available.	
There is an EIA plan.	
The EIA constraints have been identified.	

2.3.4 EIA Step 4: Conduct the environmental impact assessment exercise

Before starting EIA step 4, the Exercise Leader and the Environmental Practitioner should:

- be aware of the validation exercise plan with the EIA plan;
- have identified the environmental impacts that need to be assessed and the metrics and indicators that will be used to assess them;
- have identified the environmental tools to assess the environmental impacts;
- have already been trained on the EIA tools and process;
- be aware of all the data needed for doing EIA.

The EIA plan is executed in EIA step 4. After completing EIA step 4 the Exercise Leader should be able to draw conclusions on the environmental impact of the proposed ATM change. He-she should know how to trade off within the environmental KPA and trade-off between the environmental KPA and other KPAs. Discrepancies between the validation plan (VALP) and the exercise, the methodology used to analyse the data, and the results are summarised in a validation report (VALR).

Sub steps	Responsible Role	Roles Involved	Input	Output
4.1 Logging any event that might have affected the quality of the data of each run	Exercise Leader	• Environmental Practitioner	• Operational concept • VALP • Exercise description	• Raw data from exercise • Discrepancies between VALP and exercise
4.2 Collecting input data-files after each run, performing a quality check and transforming raw data into environmental toolset format	Environmental Practitioner	• Exercise Leader	• Raw data from exercise	• Qualified input data for the Environmental tool
4.3 Carrying out the environmental analysis	Environmental Practitioner	• Exercise Leader	• Environmental tool (e.g. IMPACT) • Qualified Input data	• EIA Results (tables and figures)
4.4 Interpreting the results	Environmental Practitioner	• Exercise Leader	• EIA results	• Conclusions
4.5 Consider Trade-offs	Environmental Practitioner	• Exercise Leader	• Results from EIA • Results from other Impact Assessments	• Trade-off within the Environment KPA • Trade-offs with other KPAs • Conclusions on trade-offs
4.6 Writing/Updating the "Environmental impact assessment" section of the validation report	Exercise Leader	• Environmental Practitioner	• EIA results • Conclusions on trade-offs • All indicators and metrics used to quantify the environmental impacts • Environmental regulations • VALR	• Update section of VALR

2.3.4.1 Logging any event that might have affected the quality of the data of each run

The Exercise Leader should:

- capture the degree to which the operational concept was really applied;
- record and explain any discrepancies between what was planned and what was done during the validation exercise;
- take into account these discrepancies – if any – when interpreting the results.

2.3.4.2 Collecting input data-files after each run, performing a quality check and transforming raw data into environmental toolset format

The Environmental Practitioner should:

- prior to running the environmental impact assessment tools, carefully check the integrity of the data that will be used for estimating the environmental impacts;
- ensure that input data is structured as expected and does not contain anomalies that will create erroneous estimates or make analysis of the estimates difficult;
- describe limitations in the quality of the data collected from the validation exercise, and the "cleaning process" applied to mitigate those limitations;
- store the raw data collected from the validation platform used as well as the data resulting from the "cleaning process";
- keep track of all input parameters and constants used for the configuration of the tools used (e.g.: Aircraft type substitutions used, Conversion factors used, etc.). Keep the log files produced in case of verification.

In some cases, due to the way the validation exercise might have been conducted, the aircraft trajectories collected might need to be completed to ensure comparability between scenarios.

2.3.4.3 Carrying out the environmental analysis

The Environmental Practitioner should:

- keep track of the environmental tool options used (default - specific); if any specific value is used, explain why default values have not been used;
- check if all required input data are available in the appropriate format;
- check the quality of the input data. In particular, identify if flight trajectory completion is required;
- register whether default data-parameters were provided as part of the input data (i.e. speed, fuel burn, etc.) rather than calculated by the environmental impact assessment tool;
- define a scope (geographical & temporal);
- run the tool;
- collect the outputs;
- check the quality of the outputs;
- collect all metrics and indicators that were not generated by an environmental impact assessment tool but that could be used to directly or indirectly measure the impacts on the environment e.g. efficiency metrics;

- collect any feedback from the participants that supports (or not) the quantitative results from the validation logbook.

	Using the environmental impact assessment tools without appropriate knowledge and training is not recommended!

As the validation exercises will conduct relative assessments, the magnitude of the impacts on the environment will be obtained by comparing:

- each solution scenario (predicted future levels implementing the proposed solution), with
- the reference scenario (predicted future levels just applying the current methods, without implementing any proposal).

	In the case of noise assessment, the Environmental Practitioner should interpret the difference in the shape and location of the noise contours.

2.3.4.4 Interpreting the results

The Environmental Practitioner should:

- use state-of-the-art statistical techniques, basic arithmetic and a lot of common sense;
- provide tables or graphs enabling the comparisons between the different scenarios evaluated;
- use recommended best practices for presenting the results (e.g. Noise contour for airports ([9]));
- interpret the results;
- identify any trade-off between environmental aspects (noise, LAQ, and emissions).

Once the results are obtained, a critical review of their reasonableness from an operational viewpoint is paramount. Are the results in line with what can be expected based on the implemented change?

In addition to this, an assessment of the significance of the results from a statistical viewpoint should be performed.

When communicating the results, only communicating an average value has its limitations and one also needs to look at a confidence interval for this average. This confidence interval is centred on the observed average and its width depends on the number of flights included in the analysis, on the dispersion of the figures making up the average and on the level of confidence for this average. Once a confidence interval is built for the trial observations and one is calculated for the measurements that are used as a reference, these two will be compared in place of comparing the average values only. If these two intervals do not overlap, then the result of the trials will be significantly different from that

[9] See Recommended Method for Computing Noise Contours around Airports, ICAO Doc 9911.

of the reference observations with a high probability (95% if you have used 95% confidence intervals). Such a process adds strength to your conclusion.

Using a lower level of confidence reduces the width of the confidence intervals: it is thus easier to get intervals that do not overlap but the strength of your conclusion will be lowered (e.g. using 80% instead of 95%).

Table 8: Typical output data representation format

IMPACTS	Typical output data representation format
Global emissions	• Global emissions are usually expressed in kg or tons of fuel burnt or of pollutant (CO_2, NO_x, PM, etc.) released. • Global emissions can be displayed geographically using the gate-to-gate 3D flight trajectories or grouped by countries, regions or region pairs.
LTO cycle emissions	• For LTO cycle emissions, the concentration of the main pollutants (NO_x, PM and VOC concentrations) is expressed in the metric, e.g. in µg-m^3. However, interpretation is necessary to translate NO_x concentrations to NO_2 concentrations required by air quality standards. • LTO cycle emissions can be displayed geographically using a Geographical Information System (GIS).
Noise	• The most frequent metrics for noise are exposure-based or equivalent noise levels, which represent the average sound level over a given period – e.g. 24h for the day-evening-night equivalent level Lden, expressed in A-weighted decibels dB(A). • Noise around an airport is often represented in the form of contour maps, showing the boundaries of zones where noise exceeds different threshold values: 55dB(A), 60dB(A), 65dB(A), etc. Wherever census data is available, population counts can be performed within each noise contour.

	When presenting the data on fuel burn and CO_2 emissions, the Environmental Practitioner should not forget that SESAR is looking at the average percentage of reduction-increase per flight.

	The data may be reported by phase of flight, aircraft type (or category), or flow of traffic (arrival, departure).

2.3.4.5 Consider Trade-offs

The work carried out by 16.03.03 – D05 (Guidance on Environmental Trade-Offs) describes the nature of trade-offs and interdependencies between the two main environmental impacts of aviation - CO_2 emissions and noise - and evaluates existing trade-off methods with regards to the context of ATM and

SESAR. The conclusion is that there are two methods deemed acceptable to support noise- CO_2 trade-off assessments in SESAR: Social Cost-Benefit Analysis and Multi-Criteria Analysis. The application of these methods is illustrated through two relevant examples in the ATM domain: departure speed constraints at Gothenburg-Landvetter and noise-abatement departure procedures at London-Heathrow. For a more detailed description of the method and tools, see Appendix C, or the SESAR 16.03.03 deliverable D05 “Guidance on Environmental Trade-Offs”.

2.3.4.6 Writing/Updating the “Environmental impact assessment” section of the validation report

As part of the validation report, the Environmental Practitioner should:

- describe all indicators and metrics used to quantify the environmental impacts;
- identify
    - if the results are as expected (and if not, why not);
    - if the results are contradictory with previous validation exercises or operational implementations;
    - if the differences observed with the expectations or previous validation exercises are due to local conditions or not;
- identify if the impacts on the environment were getting worse or reduced? Which phases of flight are concerned;
- determine if the impacts are significant and by which degree and by which criteria;
- highlight any uncertainties in the accuracy-validity of the results;
- identify what could have been done to lessen the severity of the impact and with what consequences;
- verify if the environmental impacts observed are compliant with existing environmental regulations (Table 7);
- highlight any trade-offs done between the environmental performance and other performance aspects like safety and capacity;
- scale up the results over time (one year) at least at a local level and be prepared to consider the applicability of these results at an ECAC level.
- prepare conclusions and recommendations (e.g.: what would you recommend for the next validation cycle in terms of assessment validation strategy and performance requirements?)
- contact the environmental support project for performing a review of the report.

	A decision will need to be made on whether there is an acceptable conclusion regarding the environmental implications identified in the assessment. This decision should be entered by the Focal Point in the project review form.

	For V-cycles: At the end of a cycle of validation exercises, it might be necessary to refine the expectations on environmental benefits and update the OSED description and SPR requirements in consequence.

2.3.4.7 Dos and don'ts:

- Do ask for training from the environmental support project before an EIA is performed;
- Do be sure that the data for the EIA is measured properly and available for use. Data can sometimes be sensitive and restricted for use outside an organisation;
- Don't compare metrics;
- In the case of flight trials, ensure that the behaviour of the participating airlines is comparable and also ensure that individual airline behaviour is the same for both the reference and trial flights. If not, this needs to be corrected for;
- Choose carefully which part of the trajectory to include in the analysis. Exclude the parts that are not affected by the change in order to remove unwanted influence while at the same time including sufficient part of the trajectory to cover all phases that the procedure change affects;
- Make sure that flight scenarios compared are based on a similar change in energy state, or this must be corrected for;
- Never compared planned versus actual - only planned versus planned or actual versus actual;
- When assessing departures:
  - The comparison must consider not only the fuel used to a certain distance from the airport (always after Top of Climb), but also the remaining distance to the destination after the points where procedures are compared;
- When assessing the en-route phase:
  - Consider air distance (including wind effects) rather than ground distance when assessing track shortening;
  - Consider also the vertical aspects (step climbs and optimum altitudes).
- When assessing arrivals:

  - Consider stopping the measurement at a suitable point in the final approach in order to remove the effects of pilot handling and of wind;
  - When assessing the fuel efficiency of different arrival procedures, the comparison needs to start, at the latest, from the point in the flight where the vertical profile of the two procedures to be compared start to diverge from each other (i.e. at the top of descent of the flight initiating its descent first).

- If any additional factors (e.g. the carry factor) are taken into account when communicating the results, on top of the absolute saving assessed, it must be clearly stated what is included and based on which assumptions;
- Once the results have been obtained, a critical review of their reasonableness from an operational viewpoint is paramount. Are the results in line with what can be expected based on the implemented change?
- An assessment of the significance of the results from a statistical viewpoint should also be performed. In doing so, assess the confidence interval for the results;
- Communicating the confidence interval together with the results adds strength to your conclusions.

Checklist	Checkbox
The discrepancies between VALP and the actual exercise have been noted.	
The data is 'clean' before being used the EIA tools.	
Conclusions have been drawn from the EIA results.	
Trade-offs within environmental KPA and between KPAs have been considered.	
The validation plan has been updated with results from the EIA.	
The discrepancies between VALP and the actual exercise have been noted.	
The data is 'clean' before being used the EIA tools.	
Conclusions have been drawn from the EIA results.	
Trade-offs within environmental KPA and between KPAs have been considered.	
The validation plan has been updated with results from the EIA.	

2.3.5 EIA Step 5: Scale the results up and aggregate

ⓘ	The overall Step 5 scaling-up and aggregation process is provided here for information and in a generic way. **The precise way it will be setup at a specific moment of the SESAR programme may vary. In SESAR 2020, it is described in the PJ19.04.02 – Methodology for Assessment Results Consolidation document.**

As illustrated in Figure 9, EIA Step 5 of the EIA process is about collecting the results from all individual validation exercises and aggregating them at a Deployment Package (DP) level.

It is the responsibility of the Focal Point to provide information about the potential scalability of the results of the assessment. This information will be used by the project responsible for Performance Analysis of the ATM Target Concept when scaling up to the ECAC level as carried out in Step 5. This activity is supported by specific processes, methods and domain experts, but most importantly primary and federating projects have to provide sufficient data for an accurate interpretation of validation exercise results.

The output is a deployment package document, describing scaled and aggregated results.

Sub steps	Responsible Role	Roles Involved	Input	Output
5.1 Aggregating the validation exercise results	Project manager	• Environmental practitioner • Exercise Leader	• Exercise validation results	• Scaled results
5.2 Scaling-up the results to the ECAC level	Project responsible for Performance Analysis of ATM Target Concept	• Environmental Practitioner • Exercise Leader	• Scaled results	• Aggregated results
5.3 Producing the corresponding Performance Assessment Report	Project responsible for Performance Analysis of ATM Target Concept	• Environmental expert	• Aggregated results	• Environmental impact assessment document • Performance Assessment Report
5.4 Aggregating all contributions to Fuel Efficiency, Noise and Local Air Quality	Project responsible for Performance Analysis of ATM Target Concept	• Environmental expert	• Performance Assessment report	• Aggregated fuel efficiency benefits
5-5 Aggregating results belonging to the same deployment package	Project responsible for Deployment/Performance planning and reporting	• Environmental expert	• Aggregated results	• Aggregated results at deployment package level
5.6 Producing the corresponding deployment package document	Project responsible for Deployment/Performance planning and reporting	• Environmental expert	• Aggregated results at deployment package level	• Deployment package document

2.3.5.1 Aggregating the validation exercise results

The results of individual exercises are scaled up and aggregated working from the specific subset of aircraft-ACCs-etc. that benefit from the improvement within the relevant scope of the exercise.

Further KPAs are currently being added to the Performance Framework, namely Punctuality, Civil-Military Coordination and Cooperation, Resilience and Flexibility. Gaps are filled by interpolating between results, or through expert judgement.

2.3.5.2 Scaling-up the results to the ECAC level

To complement the EIA, the results obtained in EIA Step 4 should be scaled up to an ECAC level. The project for Performance Analysis does, at least, an annual performance assessment in which the validation results for KPAs-KPIs fuel efficiency, capacity (airport, ENR, TMA), predictability and cost effectiveness[10] are aggregated up[11]. This aggregation is fairly complex but is done essentially by considering the number of aircraft-ACCs-etc. that benefit from an improvement and the magnitude of the benefit[12].

	Caution should be exercised when using this approach because benefits may not be additive, one benefit could cancel out another.

2.3.5.3 Producing the corresponding Performance Assessment Report

When the results of all the validation exercises have been scaled-up, it will become possible to aggregate the results.

Each Solution project, with the collaboration of the Project responsible for Performance Analysis, will collate all arguments and evidence about environmental benefits, then scale-up and aggregate the results to produce the Performance Assessment Report (PAR), covering all performance aspects.

	In SESAR2020, Performance Assumptions are used to aggregate/extrapolate the results obtained during validation exercises (and captured into validation reports) into KPIs at the ECAC level, which will in turn be captured in Performance Assessment Reports and used as inputs to the CBAs produced by the Solution projects. See PJ19 CI, D.4.0.1, S2020 Common Assumptions document.

The PAR records essential information collected in respect of performance. The data should correspond to OSED/SPR requirements and VALS validation objectives; a check of the coverage of OSED/SPR requirements and VALS validation objectives with the planned validation activities for Step 1 is foreseen. In addition to data available within the scope of SESAR, relevant results such as from past R&D activities, and other inputs from experts may be used to enhance and complement the quality of the performance assessment. This additional information is also recorded in the PAR.

[10] ATCO productivity
[11] So for example, an ECAC-wide fuel efficiency benefit from SESAR is determined.
[12] e.g. for fuel efficiency the kg fuel saved per aircraft for a flight phase.

2.3.5.4 Aggregating all contributions to Fuel Efficiency, Noise and Local Air Quality

The project responsible for Performance Analysis aggregates all results contributing to Fuel Efficiency (and other KPAs) in order to enable the Project responsible for monitoring overall SESAR performance against the defined targets for each SESAR concept step to perform its task.

ⓘ	In SESAR2020, this aggregation is done by PJ19.04.02 and is described in the PJ19.04.02 Performance Assessment and Gap Analysis Report.

2.3.5.5 Aggregating results belonging to the same deployment package

It is assumed that the aggregation process will be replicable at the Deployment Package (DP) level. The responsibility of this Step is still unclear but most probably it will be done collaboratively by the environmental support project & the project responsible for the Performance Analysis.

DPs are defined according to "Deployment Scenarios" (DS) i.e. with defined equipages, operating environments-locations and timeframes. Business cases will be developed for each of these DP-DS which will at least report on the different range of KPA benefits they will provide[13].

For now, noise and LAQ are not addressed in this way given that the SJU has not pushed for them to be assessed. There is no SES high-level guidance on top-down targets (unlike for fuel efficiency etc.) and they are essentially local KPIs addressing local issues.

However, it is still very useful to develop some aggregate measures if these were considered by the environmental support project to make sense.

The impact of noise and LAQ would be very relevant as inputs to the benefits reported for the DP-DS, if only using a qualitative assessment framework[14].

[13] Explicit trade-offs between the KPAs are not discussed at the time of writing, but the intention is to include such elements as the impact of necessary safety requirements on the CBA etc.

[14] E.g., a particular DP/DS is expected to have a small positive or large negative impact on noise contours around very high and high capacity airports.

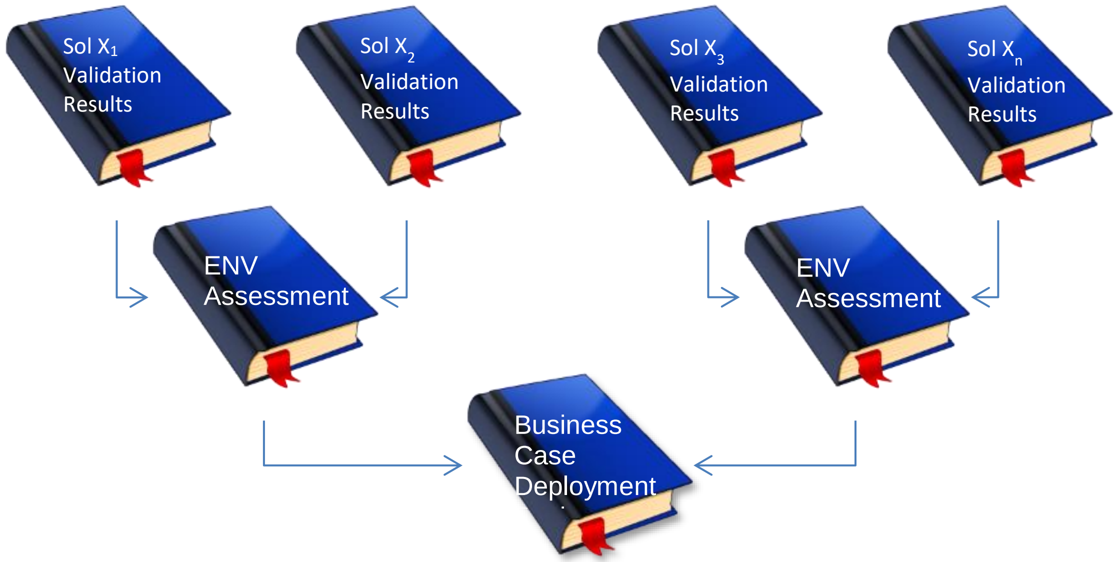


Figure 9: Aggregation of Validation Results

2.3.5.6 Producing the corresponding deployment package document

The aggregation process applied at the deployment package level should be documented.

2.3.5.7 Dos and don'ts:

- Trade-offs or weightings between KPAs are not expected to be actively studied;
- Don't scale results from local metrics.

Checklist	Checkbox
The EIA results have been scaled.	
The EIA results have been aggregated.	
The environmental impact assessment has been documented.	
A performance assessment report has been written.	
The results have been aggregated to deployment package level.	
Trade-offs have been addressed	

3 Addressing the Environmental Challenges to SESAR Implementation

The operational improvements (OIs) being developed by SESAR are expected to produce significant environmental benefits by reducing both aircraft emissions and noise impact. However, the implementation of some SESAR Solutions may trigger changes in local environmental impacts.

Although such changes may provide an overall environmental benefit they may:

- trade-off an increase in noise impact for some populations in favour of improved CO_2 performance;
- expose new populations to noise;
- increase impacts for some currently exposed populations;
- trigger actual or perceived changes in local air pollution;
- involve concentration of noise on certain populations (e.g. through PBN, SIDs, and STARs);

The public opposition which may be incited by such changes may lead to local delays, restrictions to implementation or increased costs of implementation.

Significant resistance to change in noise climate, even where an overall benefit is offered, may prevent expected performance enhancements from being implemented or may delay these whilst consultation and legal procedures take place. Distribution of noise to new areas is perhaps the most politically difficult change to procedures to attempt and this can meet significant opposition from politicians and communities.

There is also a generally increasing requirement for transparent assessment and public consultation before ATM changes are permitted or rejected. There is also a demonstrated trend in the onset of annoyance at lower levels that may lead to increasing public opposition, and thus greater requirement for consultation, even without a significant increase in actual noise impact.

In order to mitigate any such opposition to the greatest possible extent, it is essential for SESAR to engage with local operational stakeholders, who in turn should engage with local communities to communicate the impact and benefits of any proposed changes in a clear and timely manner. This should involve, but is not limited to:

- Initial assessment of local environmental impact of any implementation-related operational change (e.g. using environmental assessment models and metrics)
- Engagement with local operational stakeholders to consult on proposed operational changes, which can help towards a better understanding of potential local constraints.

Where operational improvements are identified as having the potential for a significant positive or negative change in locally significant impacts (e.g. noise around airports or over tranquil areas) – then

- Deployment planning should allow for local processes and consultation requirements where these are necessary. This may involve a communication campaign and-or consultation period with local communities which can have a cost implication for deployment of the concept;
- The release should be accompanied by high-level advice to identify the risks to stakeholders that may be involved in the deployment: Transparent assessment and reporting of the range of environmental benefits and costs that may come from a proposed change can mitigate against misinformation and can positively influence local decision-making.
- If community consultation is to be used consider providing local stakeholders with a menu of options for local decision-making; this can be more fruitful than trying to impose change where there is resistance.
- The business case for these SESAR Solutions should account for potential delay and local costs in consultation or for any sensitivity analysis.

SESAR deployment planning that may change noise distribution around airports should take local decision-making and consultation into account. However, by engaging with local stakeholders and communities proactively, the risk of local opposition to operational changes can be reduced.

4 Conclusions

This document, originally developed by Project 16.06.03, the SESAR Environment support and coordination function during SESAR 1, presents a common approach to the environmental impact assessment process. Although, it has been tailored to the SESAR programme, it is in fact based on the generic process advocated by the ICAO "Guidance on Environmental Assessment of Proposed Air Traffic Management Operational Changes" (Doc 10031) and can be applied to any kind of environmental impact assessment.

The reader of this document is invited to read the appendices as they provide more detailed information about:

- Definition of Metrics;
- Environmental impact assessment tools;
- Guidance on Environmental Interdependencies and Trade-Offs; and
- Fuel efficiency assessment based on aircraft derived data from flight trials.

Applying the recommendations of this document will:

- help and guide primary projects and demonstration projects in carrying out environmental impact assessments as part of the overall SESAR validation process;
- greatly facilitate the collection of evidence-information about the potential environmental impacts of the operational concept being developed and validated by SESAR; and
- support the aggregation of the results of the environmental impact assessments at the required levels.

5 And now some references

The following documents are referenced in this document:

[1] ICAO CAEP – "Guidance on Environmental Assessment of Proposed Air Traffic Management Operational Changes" document, Doc 10031

[2] AEM user guide (available at installation of the software)

[3] P16.06.06 – D010-02 – Guidelines for Producing Benefit and Impact Mechanisms

[4] P16.06.03 – D67 – Intermediate GHG KPIs and Metrics

[5] P16.06.03 – D68 – Advanced GHG KPIs and Metrics

[6] P16.06.03 – D69 – Noise KPIs and Metrics

[7] P16.06.03 – D70 – Airport Emissions Metrics and KPIs

[8] P16.03.07 – D02 – Base-level regulatory review

[9] 16.06.03 - D72 – Second Regulatory Update.

[10] Recommended Method for Computing Noise Contours around Airports, ICAO Doc 9911.

[11] IMPACT user guide (available via the IMPACT web platform)

[12] 16.06.03 - D71 - Guidance on Environmental Trade-Offs (Ex. 16.03.03 - D05)

[13] 16.06.003 - D76 - Use of a fuel consumption formula for assessment of new airspace designs

[14] SESAR 2020 Multi-annual Work Programme

Appendix A Definition of Metrics

Metric	Definition
Delta Fuel Burn - Delta CO_2	Delta fuel burn calculates the difference between actual fuel and the ideal "Least CO_2 Trajectory (LCT)" fuel, by dividing in into different components. The base unit of measurement is the fuel burnt during a Flight Segment, expressed as components of horizontal airborne (Ground Track), vertical airborne (Vertical Profile) and ground flight phases (Taxi In, Taxi Out). The reference LCT is calculated by performance software for different kinds of aircraft. Results of Delta Fuel Burn may be aggregated in many ways, e.g. per Flight, Flight Phase, Flight Segment, ATM sector, Validation exercise etc.
Normalised CO_2 & Delta Normalised CO_2	Normalised CO_2 relies on a normalisation method which removes the impact of some external factors based on performance tables and quantitatively analyses the flights to allow flight-to-flight comparisons. One of the main applications is to place all flights in identical reference conditions to be able to make relevant comparisons. Another possible use is to assess the influence of a certain factor on CO_2 performance while putting other factors to reference values. Normalisation can be applied on actual trajectories either to directly compare their CO_2 efficiencies or to assess their CO_2 efficiencies relatively to a theoretical optimum flight ('delta' normalised CO_2). The latter case follows the same high-level logic as the delta CO_2 metric except that the actual trajectory is normalised for reference conditions.
PRU Horizontal En-Route Flight Efficiency	The horizontal en-route flight efficiency indicator takes a single flight perspective. Although flight efficiency has a horizontal (distance) and a vertical (altitude) component, this indicator only focuses on the horizontal component as this is generally of higher economic and environmental importance than the vertical component across Europe as a whole. It compares observed performance with the great circle distance, which is a theoretical flight path that could only exist if each aircraft were alone in the system and not subject to any constraints.
Average Time In Level Flight	The average time flown level on intermediate inefficient level segments in the descent phase (from Top of Descent) is a metric to measure the vertical flight efficiency of the descent phase in terms of CDO. Other variants exist such as the noise CDO: the average time flown level on intermediate inefficient level segments in the descent phase from FL75. Variants can also be used to measure the vertical flight efficiency of the climb phase.
Area of the L_{DEN}50dB(A) contour	The number of square kilometres of the Earth's surface contained within the noise contour limiting the average Day-Evening-Night weighted noise level considered to be the onset of aircraft noise annoyance.

Metric	Definition
Area of the L_{DEN}65dB(A) contour	The number of square kilometres of the Earth's surface contained within the noise contour limiting the average Day-Evening-Night weighted noise level considered to be that beyond which at least 25% of people will be highly annoyed by aircraft noise.
Area of the SEL 70dB(A) contour	The number of square kilometres of the Earth's surface contained within the noise contour limiting the single event noise level considered to be annoying.
Area of the SEL 85dB(A) contour	The number of square kilometres of the Earth's surface contained within the noise contour limiting the noise level considered to be that beyond which at least 25% of people will be highly annoyed by a single aircraft noise event.
No. of people inside L_{DEN} 50dB(A) contour	The number of people living within the noise contour limiting the average Day-Evening-Night weighted noise level considered to be annoying.
No. of people inside L_{DEN} 65dB(A) contour	The number people living within the noise contour limiting the average Day-Evening-Night weighted noise level considered to be that beyond which at least 25% of people will be highly annoyed by aircraft noise annoyance.
Area of the xx level of the NA70 contour	The number of square kilometres of the Earth's surface contained within the contour inside which more than xx event occur daily at a noise level greater than L_{Amax} 70 dB(A).
No. of people inside xx level NA70 contour	The number of people living within the contour inside which more than xx events occur daily at a noise level greater than L_{Amax} 70 dB(A).
Annoyance Score	The sum of annoyance levels for all people living within the 45dB contour around an airport.
Annoyance Change Index	A scale from +2 to -2 indicating the level of annoyance change around an airport.
Noise Dose	The Sound Exposure Level, L_{AEQ}, L_{DEN}, L_{Night} etc. received at a given point of interest over a given time period.
Instantaneous Noise Level	The noise received at a given point from a given flight (over a very short period).
Maximum Noise Level	The maximum noise level L_{Amax} from the given flight at the given point.
Percentage Highly Annoyed	The number of people estimated to be highly annoyed by aircraft noise at a given airport.

Metric	Definition
Time Above	The total time in a day that a noise level greater than L_{Amax} 70 dB(A) was received at the given point.
Number Above	The number of event occurring in a day at a noise level greater than L_{Amax} 70 dB(A) at the given point.
Number of People Experiencing "New Noise"	The number of people living within the L_{DEN} 50dB contour after the operational modification who were not inside it before.
Number of Stand-Out Events	The number events in a day where L_{Amax} is >xx dB greater than the median for the given point.
Number of Late-Landing Events	The number of aircraft landing during the designated night-time period at the airport.
APTEMS-01	Fuel and Emissions per LTO Movement
APTEMS-02	Delta Spatial distribution of emissions - Airborne LTO
APTEMS-03	Delta temporal distribution of emissions - Airborne LTO
APTEMS-04	Delta Taxi Fuel and Emissions per movement
APTEMS-05	Delta Taxi Fuel scaled to ECAC level
APTEMS-06	Delta LTO Fuel -knock on impact to destination airport
APTEMS-07	Delta Non-Aircraft Emissions

Appendix B Environmental impact assessment tools[15]

The following tools are recommended for conducting environmental impact assessments in SESAR. These tools should be used to calculate fuel burn/emissions and noise footprints on a per-flight basis.

B.1 AEM

The EUROCONTROL Advanced Emission Model (AEM) is a stand-alone model that can determine the amount of fuel burned by a specific aircraft type equipped with a specific type of engine, flying a specific 4D trajectory. It can also determine the precise by-products of burning that fuel such as: carbon dioxide (CO_2), water vapour (H_2O), oxides of sulphur (SO_X), oxides of nitrogen (NO_X), unburnt hydrocarbons (HC), carbon monoxide (CO), particulate matter (PM), and some volatile organic compounds (VOCs) such as benzene and acetaldehyde.

ⓘ	The modelling principle of AEM relies on the use of tabulated default (standard) Fuel Flow values derived from BADA, provided for different aircraft attitudes (climb, cruise, descent) and altitude layers. These tabulated data correspond to nominal/standard speed conditions (obtained from BADA). The speed information provided in the user-defined input data is only used by AEM to calculate the duration of each flight segment, which is further multiplied by the above-mentioned tabulated fuel flow values to determine the fuel burn on each segment. In particular, AEM does not adjust the tabulated default/standard fuel flow values to account for the actual speed of the aircraft on each flight segment, whereas fuel flow is directly influenced by this factor, among other flight parameters. This constitutes a major modelling limitation when assessing fuel burn/CO_2 for concepts involving speed changes, with a risk of introducing potentially large errors in fuel burn results when speeds associated with particular concepts significantly differ from the nominal BADA speed conditions implicitly assumed in the AEM Fuel Burn calculation. More information about AEM may be obtained from EUROCONTROL at aem@eurocontrol.int.

B.2 Open-ALAQS

The EUROCONTROL Open-ALAQS tool is an airport local air quality tool based a GIS (Geographical Information System) that simplifies the process of defining the various airport elements (runways, taxiways, buildings, etc.) and allows the spatial distribution of emissions to be visualised. The tool provides a four-dimensional emission inventory for an airport in which the emissions from the various fixed and mobile sources are aggregated and subsequently displayed for analysis. Once the emissions inventory has been established, dispersion modelling (provided by the German Federal Agency model AUSTAL2000) can be used to calculate pollutant concentrations on the airport and in the surrounding area throughout a day. The system is thus compatible with legislative requirements for 8-hour, 24-hour, and annual mean values of pollutant concentrations.

Open-ALAQS/AUSTAL2000 is the first complete open-source airport local air quality tool suite (emissions inventory, concentration and dispersion).

ⓘ	More information about Open-ALAQS may be obtained from EUROCONTROL at open-alaqs@eurocontrol.int.

[15] AEM, Open-ALAQS, V-PAT and the IMPACT web application are subject to the IPR of EUROCONTROL.

B.3 V-PAT

The EUROCONTROL Vertical Profile Analysis Tool (V-PAT) supports the assessment of flight compliance with continuous descent and continuous climb profiles and calculates the fuel burn and emissions impacts of level flight at non-optimal levels.

The V-PAT tool may be calibrated by user-defineable parameters for both pre-and post-processing. Such parameters include the definition of the vertical scope for analysis, data validation settings, analysis criteria validation and result formatting. V-PAT also makes estimates of the fuel consumed during climbs and descents using the latest BADA 4 data tables. It uses surveillance data from either an ASTERIX, ETFMS, or various ADS-B sources to measure the flight profile. For every flight in the input, an analysis is performed, and the following measurements are made available: flight duration, amount of time / distance in level flight below top of climb / top of descent, and the fuel burn / CO_2 impacts of such level flight.

Vertical flight efficiency (Climb / descent and en-route)

Vertical flight efficiency in the climb and descent phases is the relative difference between an aircraft's actual vertical profile and the same aircraft's optimal vertical profile. It is assumed that the optimal climb profile consists of an uninterrupted climb at an optimal engine thrust setting whilst an optimal descent profile consists of an uninterrupted descent at an engine idle thrust setting. In practice, such optimal profiles may not be able to be flown in order to maintain safety or due to inefficient pilot practices, procedures or airspace restrictions.

Vertical flight efficiency in the en-route phase is the relative difference between an aircraft's actual vertical profile and the same aircraft's vertical optimal profile. It is assumed that the optimal profile consists of a gradual cruise climb to the optimal cruise level as the weight of the aircraft gradually falls, until its optimum top of descent point. In practice, cruise climbs / descents are not practicable under normal operations as they block too many flight levels In addition, operational restrictions and sector capacity limits, which do not allow aircraft to cruise at their optimal level, may exist to regulate the number of aircraft in a sector at any one time in order to maintain the overall capacity of the network.

Operational improvements advocated by SESAR to improve vertical flight efficiency in the climb / descent phases include Continuous Climb Operations (CCO) and Continuous Descent Operations (CDO). Despite a majority of operational stakeholders (e.g. ACI, CANSO, IATA, ICAO, SESAR and NextGen) championing the fuel (CO_2)-saving benefits of performing CCO and CDO, there is currently no common definition of, or harmonised measurement for, CCO and CDO achievement within SESAR.

European Taskforce on CCO / CDO

In 2015, a European Taskforce on CCO / CDO was established, chaired by EUROCONTROL with participation from a wide range of European operational stakeholders. The objectives of this taskforce were to agree on a harmonised European definition of CCO / CDO achievement together with agreeing on harmonised parameters to be used in the measurement of CCO / CDO across Europe.

	The Taskforce concluded by defining both CCO and CDO in accordance with the environmental impact of each procedure, namely the identification of both noise and fuel CCOs and CDOs. The basic premise of these definitions is that the entire climb and descent profiles should be considered for CCO / CDO measurement for fuel CCO / CDOs whilst noise CCOs / CDOs should be measured to FL105 (CCO) or from FL75 (CDO), in alignment with the guidance on environmental assessment detailed in the SESAR ERM. The taskforce also agreed on harmonised definitions of CCO and CDO achievement with defined parameters and using a metric of average level time per aircraft per level band. Whilst accepting that stakeholders may be subject to local regulations for measuring CCO / CDO performance, stakeholders are strongly encouraged to follow the harmonised definitions and parameters of the Task Force when measuring and sharing results on CCO / CDO performance at the international or pan-European level in order to allow a harmonised comparison of vertical profile efficiency performance across SESAR airspace, in the place of the current fragmented criteria that exist across Europe.. It will also allow the possibility of comparing both intra-FAB and inter-FAB performance and offer an opportunity to assess the performance of ATM functionalities which cover the development and implementation of fuel efficient and/or environment-friendly procedures for arrival and departure as detailed in the PCP (Pilot Common Project) regulation (716/2014).To assist SESAR stakeholders with understanding the various outcomes of the taskforce, an animation a has been created which describes the various definitions and parameters agreed by the taskforce whilst several new reference points have been developed to enable a more simplified identification of the ToC (Top of Climb) and ToD (Top of Descent) points. This is available at https://www.eurocontrol.int/concept/continuous-climb-and-descent-operations. The CCO / CDO Task Force is responsible for the European CCO / CDO Action Plan, the CCO / CDO State of Play Report and the CCO / CDO Tool Kit (a website of resources to support CCO / CDO implementation. **V-PAT** The definitions and parameters agreed by the CCO/CDO Taskforce have been defined within V-PAT, whilst the V-PAT analysis engine also includes a robust algorithm for calculating level flight segments independent of data source or granularity.

ⓘ	**It is recommended to use V-PAT for conducting CCO/CDO assessments in SESAR 2020.** More information about V-PAT may be obtained from EUROCONTROL at v-pat@eurocontrol.int.

B.4 IMPACT

IMPACT is a web-based modelling application used to assess the environmental impacts of aviation, and whose development, initiated in the context of the SESAR 1 programme, has since been steered and carried out by EUROCONTROL. It allows the consistent assessment of trade-offs between noise and full-flight gaseous emissions thanks to a common advanced aircraft performance-based trajectory model using a combination of the ANP database and the latest release of the BADA family. CO_2, NO_X, HC, CO and PM emissions are computed using the LTO emission indices in the ICAO Aircraft Engine Emissions Databank and FOI Turboprop Emissions database combined with the Boeing Fuel Flow Method 2 (BFFM2). PM emission indices of jet engines are estimated using the First Order Approximation (FOA3.0) method. Both BFFM2 and FOA3.0 methods are detailed in the ICAO Airport Air Quality Manual (Doc 9889).

IMPACT successfully underwent the CAEP assessment process and is now used at the ICAO CAEP level to support fuel/emissions and noise assessments.

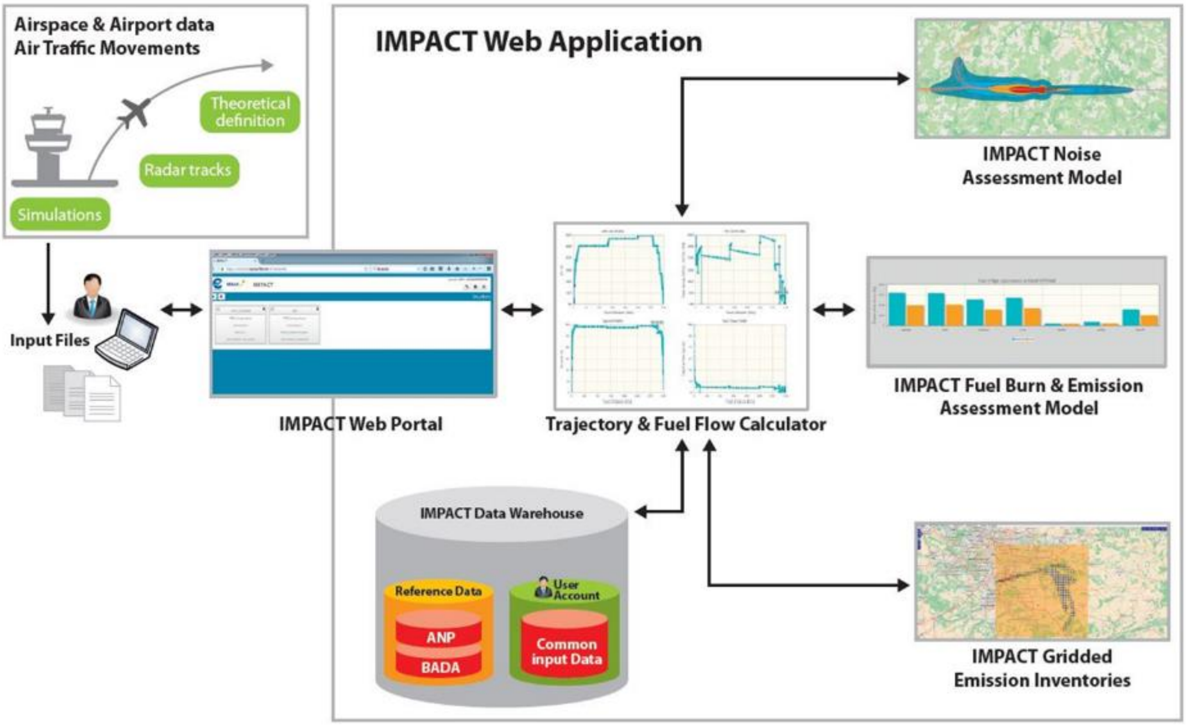


Figure 10: IMPACT web-based modelling application

ⓘ	More information about IMPACT may be obtained from EUROCONTROL at impact@eurocontrol.int.

Appendix C Summary of Guidance on Environmental Interdependencies and Trade-Offs

C.1 Structure

This appendix provides a high-level lay person's guide to issues around environmental interdependencies and trade-offs. Following a discussion of the basic issues, the relevant methodologies for assessing these interdependencies are considered and evaluated. In the case of the preferred methodologies, these are applied to two case studies in turn and the results are considered. For a more detailed consideration of the analytical and theoretical underpinnings to the issues and methods discussed, see the SESAR 16.03.03 deliverable D05 Guidance on Environmental Trade-Offs.

C.2 Background

The SESAR Programme has endorsed ambitious environmental goals to be achieved through the implementation of new ATM concepts eventually enabling performance-based operations. SESAR seeks to reduce the average emissions of greenhouse gases per flight and to better manage noise impact. The final target for SESAR is to enable 10% fuel savings per flight from ATM improvements alone, producing an average 10% reduction in CO_2 emissions per flight. When associated with thrust reduction, these fuel savings should also serve to reduce local pollutant emissions such as nitrogen oxide and particulate matters. Recognising that major airports are already bound by significant noise regulations, SESAR aims to achieve these emissions reductions with, at minimum, zero impact on noise and, preferably, further mitigation such that population exposure to noise is minimised to the greatest extent possible.

C.3 Local and Global environmental impacts

At a local level, there may be interdependencies between these environmental impacts such that the reduction of one impact may come at the cost of another. Without any overall performance framework to prioritise the mitigation of these impacts, public perception is often the determining factor in local environmental regulation, and has the potential to alter the performance of the ATM network in the area. This is particularly significant where noise and CO_2 have to be traded as the immediacy and tangibility of noise impacts have led to a strong public focus on this issue, which can jeopardise the delivery of CO2 benefits from the new concept to be deployed.

In this context, and given that climate change is a global issue best addressed by large-scale mitigation initiatives, there is a clear priority set by SESAR on achieving its CO_2 target. The Programme aims at providing technical and operational solutions which will directly contribute to improving average flight efficiency over Europe and reduce the absolute contribution of ATM to aviation's CO_2 emissions.

By contrast, SESAR does not intend to set targets on noise and local air pollution. This is because these are local issues whose actual impacts depend on the specific environmental circumstances around individual airports. SESAR is developing ATM concepts which will enable the reduction of local noise and air pollution impacts, but the extent of such reductions is wholly dependent on how these concepts are implemented locally.

In order to achieve its environmental objectives and its CO_2 targets, SESAR seeks to support the stakeholders responsible for the deployment of the operational concepts that the Programme develops. The objective is to ensure that the actual delivery of benefits in daily operations (with SESAR concepts deployed) is in line with the benefits estimated in validation exercises during the development phase. While SESAR does not manage this implementation phase, it does intend to provide advice and guidance on how to consider interdependencies at a local level so that SESAR environmental objectives are met. As implied above, it is not expected that generic rules will be applied to manage local environmental impacts such as noise and air pollution.

Solutions to address noise and curb aviation emissions can be either technical or operational. The focus here is on operational solutions brought about by new ATM concepts to reduce noise and-or CO2 emissions.

C.4 Description of Trade-off and Interdependencies

In the Nature of Trade-Offs Report (Project 16.03.03 - D02), four types of interdependency between noise and emissions are described:

- **Less CO_2 - Less noise**

This is obviously the most preferred outcome of any operational change. An example of an ATM concept which might reduce both CO_2 emissions and noise is the implementation of more efficient climb and descent procedures.

- **More CO_2 - Less noise**

This scenario covers noise reduction measures which increase fuel burn and therefore also CO_2 emissions. This is a common situation around airports due to the strong position of noise lobbies. Implementation of noise restriction measures requires aircraft to fly around populous areas, burning more fuel than would otherwise be necessary. Examples that are relevant to the ATM domain are noise preferential routes, whereby traffic is concentrated over less populated areas, and higher take-off thrust to clear communities around the airport quicker.

- **Less CO_2 - More noise**

These scenarios reduce CO_2 emissions, but with the penalty of increasing local noise. This would encompass any form of direct routing aimed at fuel efficiency, where implementation took no account of the noise impact on the communities below. If these direct routings relate to approaches to airports then there is a strong possibility of producing detrimental noise impacts.

- **More CO_2 - More noise**

The least favourable scenario is the one in which an operational change leads to an increase in both CO2 emissions and noise. Where such changes are implemented, the detrimental effects are either unintentional or traded-off against other factors, such as safety or cost.

C.5 Decision making methods

Weighing the effects of CO_2 emissions and noise against each other cannot help but be a political process. However, the analytical side of the social sciences provides tools that can support this process; among the scientific literature many methodologies can be found. P16.03.03 D05 describes in some detail the most relevant methodologies. Of necessity it cannot be an exhaustive list but those of most likely applicable to the issues considered in this document have been selected. Four main monetary techniques and two non-monetary techniques have been identified, as follows:

- Cost Effectiveness Analysis (CEA)

- Cost Utility Analysis (CUA)
- Data Envelopment Analysis (DEA)
- Social Cost Benefit Analysis (SCBA)
- Impact Assessment (IA)
- Multi Criteria Analysis (MCA)

In most of these methods, some form of weighting is incorporated which implies that a degree of subjectivity is used to consider the social welfare element, whether implicitly or explicitly. The weightings differ between methods.

C.6 Summary

The work detailed in by 16.03.03 – D05 (Guidance on Environmental Trade-Offs) describes the nature of trade-offs and interdependencies between the two main environmental impacts of aviation - CO_2 emissions and noise - and evaluates existing trade-off methods with regards to the context of ATM and SESAR. The conclusion is that there are two methods deemed acceptable to supporting noise- CO_2 trade-off assessments in SESAR: Social Cost-Benefit Analysis and Multi-Criteria Analysis. The application of these methods is illustrated through two relevant examples in the ATM domain: departure speed constraints at Gothenburg-Landvetter and noise-abatement departure procedures at London-Heathrow. For a more detailed description of the method and tools see the SESAR 16.03.03 deliverable D05 "Guidance on Environmental Trade-Offs".

Appendix D Fuel efficiency assessment based on aircraft derived data from flight trials

D.1 Purpose of this appendix

This appendix focuses on assessing the fuel efficiency of flight trials, based on aircraft derived data. This is a challenging task and, at the same time, a very important part of processing the results of the activities. There are many pitfalls in conducting a fuel efficiency analysis that could cause incorrect or directly misleading results if not avoided. This appendix aims to give concrete guidelines, dos and don'ts and highlight common traps.

D.2 Introduction

When conducting a flight fuel efficiency analysis, the aim is to assess what impact the new concept of operation has on a flight's fuel consumption. This change can be a new flight procedure, the use of new technology, the use of improved meteorological data etc. and it can concern any phase of the flight (taxi out, departure, cruise, arrival or taxi in). There are several approaches to how this can be achieved. A theoretical analysis can be performed, surveillance information (e.g. radar data) can be used in combination with a theoretical analysis or with modelling of fuel consumption, or the fuel consumption of actual flights can be measured and analysed based on aircraft derived data. In this appendix we focus on the last of these, the analysis of aircraft derived data from flight trials.

Which data source the analysis is based on (e.g. flight recorder data or secondary surveillance radar data) has an impact on the level of granularity that the analysis can be performed with, and also on the possible accuracy of the flight trial results. As a general rule, it can be stated that the accuracy of the output can never be higher than the accuracy of the input.

In order to identify any effect on fuel consumption due a new concept of operation, data must be available both for flights affected by the change and for flights not affected by the change. Hereinafter, these will be referred to as the trial flight dataset and the reference flight dataset. Selection of suitable reference and trial flight datasets requires careful consideration.

Many parameters affect an aircraft in flight and in order to be able to perform a correct analysis it is important that as many parameters affecting the result as possible be available and taken into account.

Further, it is important to select the appropriate part of the flight for inclusion in the analysis. By excluding parts of the flight not affected by the change, many error sources can be removed. At the same time, enough of the flight needs to be included for all the effects of the change to be considered.

In order to have correct results, it is important that the scenarios being compared are comparable. This might sound obvious and simple but there are many examples from previously conducted flight trials where "apples" have been compared with "oranges" because of how the reference flight dataset was chosen, which part of the flight trajectory was used or because of certain parameters affecting the flights not being handled.

Finally, once the results are obtained, an assessment of their reasonableness is important. It is also advisable to assess the confidence in the results and to communicate this together with the actual results.

If flight recorder data is needed for the analysis, it is important to keep in mind that it is generally viewed as sensitive information. It is not uncommon for an agreement from the pilot union within the company to be necessary to use it for such purposes. This is something that needs to be considered early in the process in order for any agreements needed to be in place in time for conducting the analysis.

The topics above will be further explored later in this appendix. However, to start with, we give an example showing the challenge of verifying small fuel savings in the scatter of other factors affecting fuel burn.

D.3 The challenge

We will use data from an assumed flight trial (made up figures) conducted on the Stockholm-Oslo (ARN-OSL) route and, as reference flights, flight data from 301 actual flights conducted on the same city pair.

The distribution of fuel burn for the reference flights is illustrated in Figure 11. The average fuel burn for these ARN-OSL flights is 1682 kg. The median[16] flight burnt 1669 kg. However, we note a large variance of fuel burn. Although the material is limited to a single aircraft type, we have some flights burning just above 1400 kg (15% less than the average) and we have two flights consuming almost 40% more than the average fuel on the same route. This spread is caused by the large number of factors affecting fuel burn on a given flight. Examples of such factors are, gross mass, wind, icing conditions, temperature, ATC, other traffic, runway combinations, pilot performance, aircraft centre of gravity, technical condition of airframe and engines of individual aircraft within the fleet, etc.

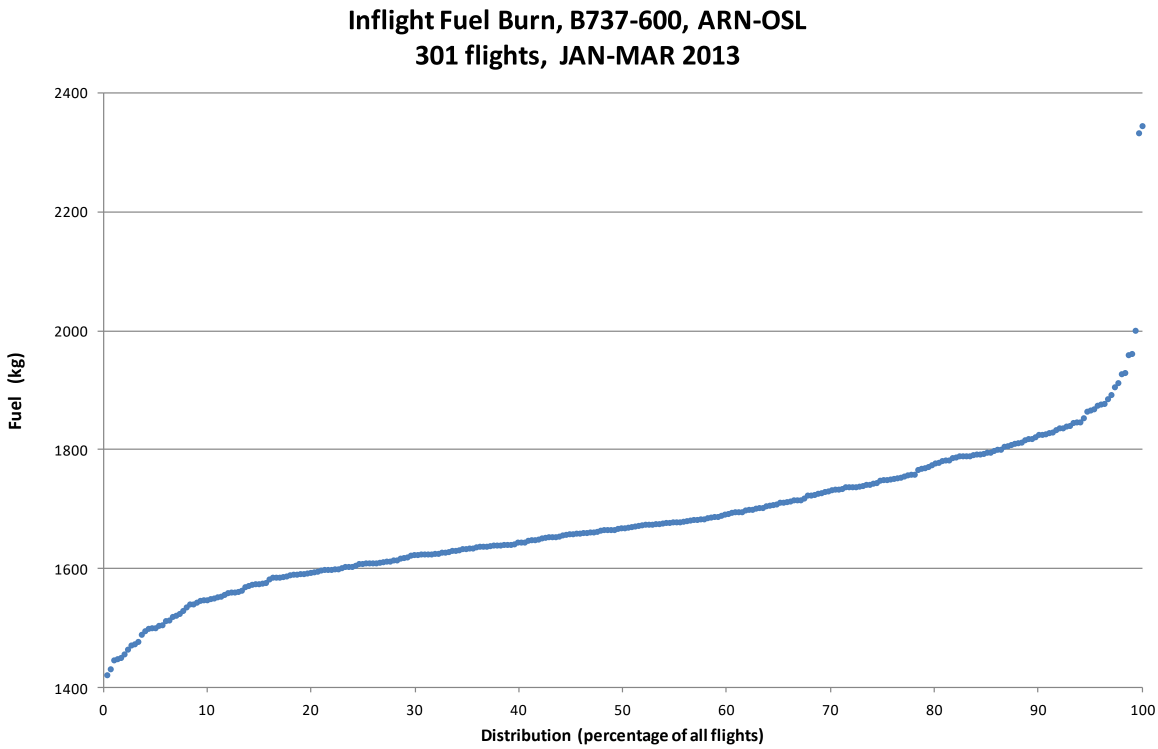


Figure 11: Distribution of fuel burn on actual flights

16 In statistics and probability theory, the median is the numerical value separating the higher half of a data sample, a population, or a probability distribution, from the lower half. The median of a finite list of numbers can be found by arranging all the observations from lowest value to highest value and picking the middle one (e.g., the median of {3, 3, 5, 9, 11} is 5).

The challenge when evaluating the results of flight trials is to identify a small effect, often in the order of a single percent, against the background of normal variance, which here is -15% to +40% of the average flight fuel burn.

D.4 Type of data to use for the analysis

D.4.1 Approaches to fuel burn calculation

The most common approach when assessing the fuel efficiency of flight trials is to use fuel flow or fuel burn parameters from some data source.

D.4.2 Flight recorder data versus secondary surveillance radar data

The primary data sources used for fuel efficiency assessment, where the analysis is based on fuel burn information, are aircraft flight recorder (FDR) data, different kinds of Automatic Dependent Surveillance (ADS) data and secondary surveillance radar (SSR) data. The higher the accuracy of the input in the fuel efficiency analysis, the higher the accuracy the output can have.

Therefore, FDR data with detailed information on the flight is highly preferable. Using SSR data and then simulating the fuel consumption for the flight will most likely never be as accurate as when aircraft-derived data is used. E.g. it is not be possible to capture the use of speed brakes during descent or when and how the aircraft is configured for landing (extension of movable surfaces on the wings and landing gear extension) using SSR data. Another example is individual aircraft characteristics such as aircraft mass etc. If an erroneous assumption of aircraft mass is made, the results of a simulated validation might not represent what would be achieved in the real world with other aircraft masses. If an arrival or approach procedure to be flown is designed for very heavy aircraft (e.g. where altitude constraints are placed in relation to the remaining distance to fly) the procedure might be efficient for these very heavy aircraft while the efficiency for lighter aircraft will be far from optimal.

D.4.3 Tolerances of measuring systems and data accuracy

It is important to keep in mind the accuracy of the input parameters (such as fuel flow, gross mass etc.). As stated earlier, the accuracy of the output can never be higher than the accuracy of the input.

D.4.4 Challenge of flight recorder data

FDR data is generally viewed as sensitive information. It is not uncommon for an agreement from the pilot union within the company to be necessary to use it for purposes outside its core intended use (usually flight safety monitoring). In order to facilitate such an agreement it might be wise to anonymise the data by removing the flight number, date and flight crew details. If flight number and date are removed, it is highly advisable to give each flight a unique sequence number, in order to be able to look up the flight date and time during the analysis (e.g. to be able to identify which flights were flown in high traffic density and which were flown in low traffic density).

FDR data can be extremely accurate, but also grossly misleading if not handled professionally. It is recorded in the aircraft second by second (or with a frequency higher or lower than that). On the ground, the data must be “transcribed” from data memories to a readable format. Most often, the transcribed files need to be further processed to aggregate the second-by-second data into sums or averages suitable for analysis or to identify specific events, e.g. use of speed brake, landing gear extension etc. Both these processes, the transcription and the aggregation, can be subject to errors, especially when the original data from the aircraft suffers from anomalies or imperfections not anticipated when creating the algorithms. Make sure that these processes can correctly handle abnormalities like interruptions in the data flow or spikes in the data (unrealistic parameter readings for very short times). Verify that absent data is handled correctly (e.g. represented by NULL values and not the number zero). Question the data quality before use!

D.5 Reference and trial flight datasets

Choosing suitable reference and trial flight datasets is paramount. The reference and trial datasets should contain the same aircraft type. The more the two datasets are similar, the fewer factors might need to be compensated for in order to identify the fuel efficiency difference correlated to the change to be assessed. E.g. if both the reference and trial flight datasets contain flights conducted only in low traffic density it is not necessary to compensate for this. But if the reference flight dataset contains flights conducted in high traffic density and the trial flight dataset contains flights conducted in low traffic density, the effect that the traffic density has on the fuel consumption needs to be taken into account in order to obtain reliable results.

The size of the datasets should preferably be large in order to even out the effects of parameters that cannot be handled but that might influence flights differently and randomly. In large datasets these effects should affect both the reference flights and the trial flights in a similar way.

If more than one operational improvement is introduced at the same time and the improvements affect the same flight phase, it becomes difficult to assess the fuel efficiency improvement linked to each unique change when comparing the reference flights with the trial flights. Therefore, if possible, try to compile reference and trial flight datasets where only one operational improvement differs (or if there are different improvements make sure they do not overlap on some part of the flight). Trying to filter out the effect of one operational improvement amongst several should be avoided due to the difficulties involved and thereby the risk of incorrect results.

Beware of trial flights being treated as “royal flights”. If they are given priority compared with other flights, there is a risk that this will contribute positively to the efficiency of the flight. In the end, this can lead to an over optimistic result when the impact of the operational change is assessed.

Never compare planned versus actual outcome (e.g. fuel consumption according to flight plan versus actual fuel consumption) but always planned versus planned or actual versus actual outcome. In comparing planned versus actual outcome, it is not possible to assess how much of the identified saving would have been realised anyway (without the new procedure) since shortcuts etc. are often given by ATC, resulting in the actual outcome being better than the planned outcome even without an operational improvement present.

D.6 Parameters affecting the results

D.6.1 Different approaches to handling these parameters

As illustrated in the section “The challenge” above, many parameters affect the fuel consumption of a flight. In order for the fuel consumption between two flights to be comparable, these factors must be taken into account. Comparing the absolute fuel consumption from a given point in cruise of a flight cruising at FL390 with 50 knots headwind and a mass of 78 tons with the fuel consumption of a flight cruising at FL320 with 30 knots tailwind and a mass of 65 tons will not reveal which flight was most fuel efficient. Due to the factors affecting the fuel consumption of the flights (cruising FL, wind and aircraft mass etc.), the one with the higher absolute fuel consumption might actually be the most efficient one.

Do nothing – direct comparison

If directly comparing the recorded fuel values, the comparison will be affected by all differences between the two sets of flights. Individual flights in the two sets can be affected, to a large extent, by variations in gross mass, wind, flown speed, etc. This is illustrated in Figure 12 where the trial flights (represented by squares in the box on the left) are compared directly with the reference flights (represented by dots in the box on the right). The different colours of the dots and squares represent the differences in fuel consumption between the flights due to the many factors affecting the flights.

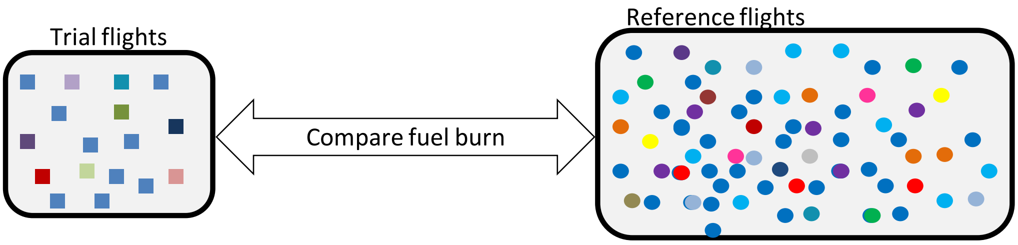


Figure 12: A set of trials lights and reference flights

In normal cases, this is not an advisable approach to adopt due to the difficulty in identifying the fuel efficiency difference caused by the change introduced, with so many factors affecting the absolute fuel consumption. However, if the reference and the trial datasets are large and similar (conducted in similar conditions with the same spread of variation of the factors affecting the fuel burn in the two datasets), a direct comparison could give some usable results.

Comparison of normalised values

One way to handle different factors is by finding the mathematical relationship for how the different parameters affect the fuel consumption of the flight. The actual fuel consumption of the flights are then re-calculated (using these mathematical relationships) to represent the fuel consumption of a flight for a given set of conditions (mass, meteorological conditions, cruising altitude etc.) that are kept the same for all flights. This is called normalisation.

After normalisation of the factors having the largest impact on fuel burn, the difference between individual flights in the two datasets has been reduced. This is illustrated in Figure 13 by more homogenous colours of the squares and the dots. The two sets of flights are now more comparable and it will be easier to detect the difference in fuel burn that we are trying to identify. However, the method of normalisation can be a source of errors. Finding the correct mathematical formulas for how each parameter affects the fuel burn is not trivial and if incorrect formulas are applied, the result will also be incorrect.

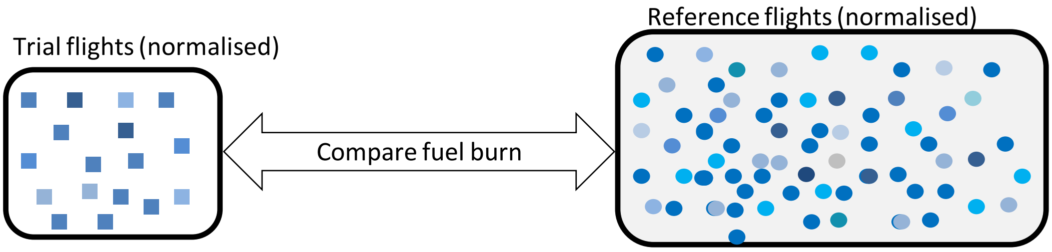


Figure 13: A set of trials flights and reference flights that have been normalised

Comparison of difference between actual flights and theoretically optimum flights

Another way of handling factors affecting the fuel consumption of a flight is to use a very accurate performance model for the aircraft type in question (the aircraft manufacturer performance software) to do the normalisation.

With this method, each flight in the two sets of flights is compared to a theoretical optimum flight calculated with an aircraft performance software tool. The theoretical optimum flight and associated fuel burn is calculated for the same conditions as those the real flight was exposed to. This will allow more accurate consideration of a large number of factors such as gross mass, wind, temperature, and some of the inaccuracies associated with normalisation can be avoided. A difference in fuel burn (hereafter known as delta fuel burn) between the actual flight and the theoretically optimum flight is calculated for each flight. The effect we are looking for is sought in the difference in average deltas for the reference and trial datasets.

To illustrate this with an example, we look at a situation where a new arrival procedure is introduced. Suppose the average delta fuel burn between the actual flights and the theoretical optimum flights under the same conditions in the reference flight dataset (flying the old procedure) is 150 kg from a certain point in cruise up to landing. At the same time, the average delta fuel burn between the actual flights and the same theoretical optimum under the same conditions in the trial dataset (flying the new procedure) is 90 kg from the same point in cruise. The difference in fuel consumption between the two procedures is then 150-90 = 60 kg, i.e. there is a fuel saving of on average 60 kg per flight from the specified point in cruise associated with the new flight procedure.

The delta fuel burn concept is illustrated schematically in Figure 14.

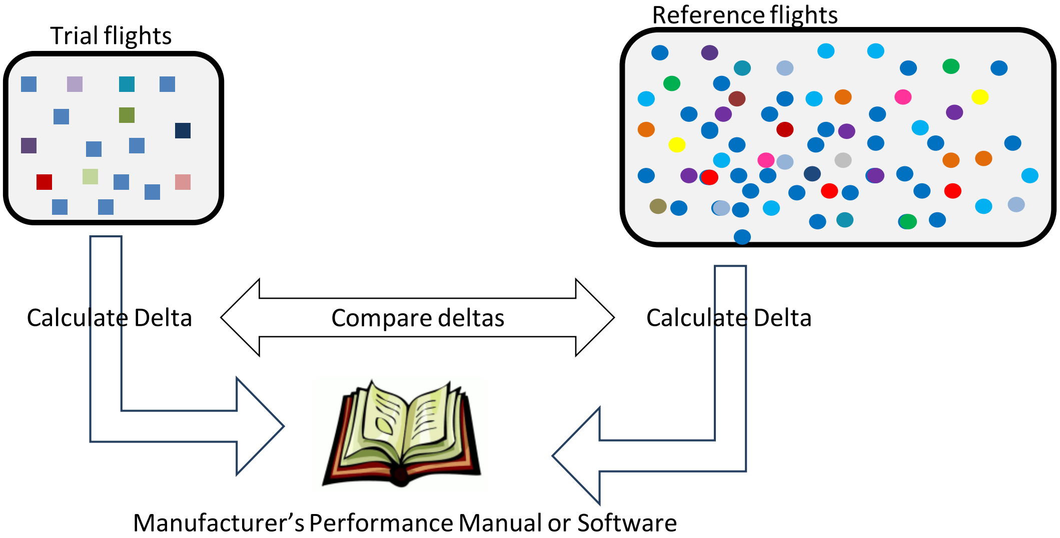


Figure 14: A set of trial flights and reference flights that are analysed with a delta burn method

One large advantage of the delta burn methodology is that you leave the complex task of normalisation to a very precise performance model instead of finding out the mathematical relationships yourself.

D.6.2 Parameters that need to be considered

As mentioned earlier, many parameters affect the fuel consumption of a flight. This section contains a non-exhaustive list of parameters that need to be considered.

Aircraft mass

The aircraft mass has a direct impact on the fuel consumption of a flight. E.g. in the en-route phase, a higher mass will result in higher fuel consumption at a given altitude compared to a similar lower mass flight mission. In most cases, this parameter needs to be corrected for.

Meteorological variability

Wind affects not only the individual flight but also the traffic capacity of the airport. Comparing trial flights performed under weak wind conditions with reference flights with other wind conditions can give erroneous results. Both variations in strength and direction of the wind must be considered. For the individual flight, the fuel consumption is affected by the headwind-tailwind component. A flight in strong headwind conditions will spend a longer time in the air going between two points than a flight in tailwind conditions (it will travel a longer air distance). This must be compensated for. Flights following a geometric profile (e.g. a final approach segment of a 3° glide slope) will also be affected by the headwind component. In strong headwind conditions partial thrust might need to be applied in order to follow the geometrical segment while in other conditions idle thrust might be sufficient.

Aircraft operation above transition altitude is associated with flying on a standard barometric setting of 1013 hPa. However, close to the airport a local altimeter setting (QNH) is used to have a more correct altimeter reading. An aircraft operating at FL360 in a high pressure region (i.e. where the local QNH is above 1013 hPa) will have a true altitude greater than 36000 feet. Each change in air pressure of 1 hPa corresponds to approximately 30 feet. Thus, if the local QNH is 1023 hPa, an aircraft operated at FL360 in this region will be at approximately 36300 feet above the reference altitude (i.e. sea level). This will affect the aircraft performance and the potential energy of the aircraft. On the contrary, if the aircraft is operated in a region with a low atmospheric pressure, e.g. QNH 983 hPa, the aircraft at FL360 will have a true altitude of 35100 feet above the reference altitude (i.e. sea level). The aircraft altitude therefore needs to be corrected for the actual QNH to have comparable altitude information.

The air temperature affects the density of the air which in turn affects the fuel consumption. ISA deviation of the temperature therefore needs to be corrected for. To summarise, the temperature and the air pressure affect the density altitude were the aircraft is operated, and this needs to be catered for.

Flight in icing conditions requires the use of engine anti-ice and sometimes also wing anti-ice. Anti-ice affects the fuel consumption of a flight. For a typical single aisle aircraft the difference between using and not using engine anti-ice during descent is of the order of 30 kg. If both engine and wing anti-ice is used, the figure is considerably higher. It is not uncommon that the fuel efficiency improvement the validation is assessing is of the same magnitude. Anti-ice must therefore be taken into account in order for the results to be correct.

Convective weather-squall lines might cause circumnavigation of convective clouds along the intended route. This will affect the distance travelled (it might make it longer or shorter depending on the intended route and the location of the adverse weather regions and how they are circumnavigated).

Tail number variability

Different individual aircraft have different characteristics that might influence the fuel consumption. Make sure to take this into account and correct for it. The following is examples of such characteristics:

- Performance degradation due to aging, resulting over time in an increased fuel consumption of the individual aircraft compared with a brand new aircraft;
- Wing tip devices (winglets-sharklets) or not;
- Engine type and associated thrust rating.

Aircraft centre of gravity

Depending on aircraft type, the centre of gravity of the aircraft has a varying degree of impact on the fuel consumption. In general, an aircraft centre of gravity is preferable from a fuel efficiency perspective.

Traffic density

High traffic density often creates increased amount of tactical intervention from ATC (radar vectoring), level flight, aircraft assigned speed etc. that in turn affects fuel efficiency. Therefore, the traffic density needs to be considered for the flights to be compared.

Traffic direction in relation to the procedure design

The direction from which the traffic arrives into the TMA might influence where on the arrival procedure the aircraft will join the procedure (i.e. if shortcuts are given to a waypoint later than the first point of the arrival procedure). Make sure to take this into account when comparing the efficiency of two procedures. Figure 15 displays the RNP AR procedure into Runway 26 at Stockholm Arlanda airport. Traffic arriving from the northwest is often cleared direct to the point SA502 (marked “2”) whereby the distance to the arrival runway is shorter- “more green” than for traffic arriving from the west joining at ELTOK (marked “1”) (the starting point of the arrival procedure).

Pilot behaviour

Pilot behaviour such as when and how the aircraft is configured, use of speed brakes, FMS handling (use of different FMS modes, trajectory handling) etc. will affect the fuel consumption of a flight. This factor is not so easy to compensate for. In a large-enough dataset, the effect of pilot behaviour will hopefully be similar in the reference flights and in the trial flights. One way of reducing the effect that pilot behaviour has on the flights, though, is to exclude the parts most affected by this if their inclusion is not important for the assessment of the flight procedures. E.g. when assessing the fuel efficiency difference between two arrival procedures, removing the final approach phase from approximately 2500 feet to landing will remove a segment of the flight that probably does not differ greatly between the two procedures (typically a fixed 3° geometric descent segment) but which is greatly affected by how and when the pilot configures the aircraft for landing. In addition to the piloting technique, this segment is also affected by the wind component along the trajectory since it is a geometrical segment (i.e. in strong headwind conditions thrust will need to be applied to follow the 3° profile while in other conditions it might be possible to fly the segment with idle engine thrust). It might therefore be wise to remove the segment from the assessment.

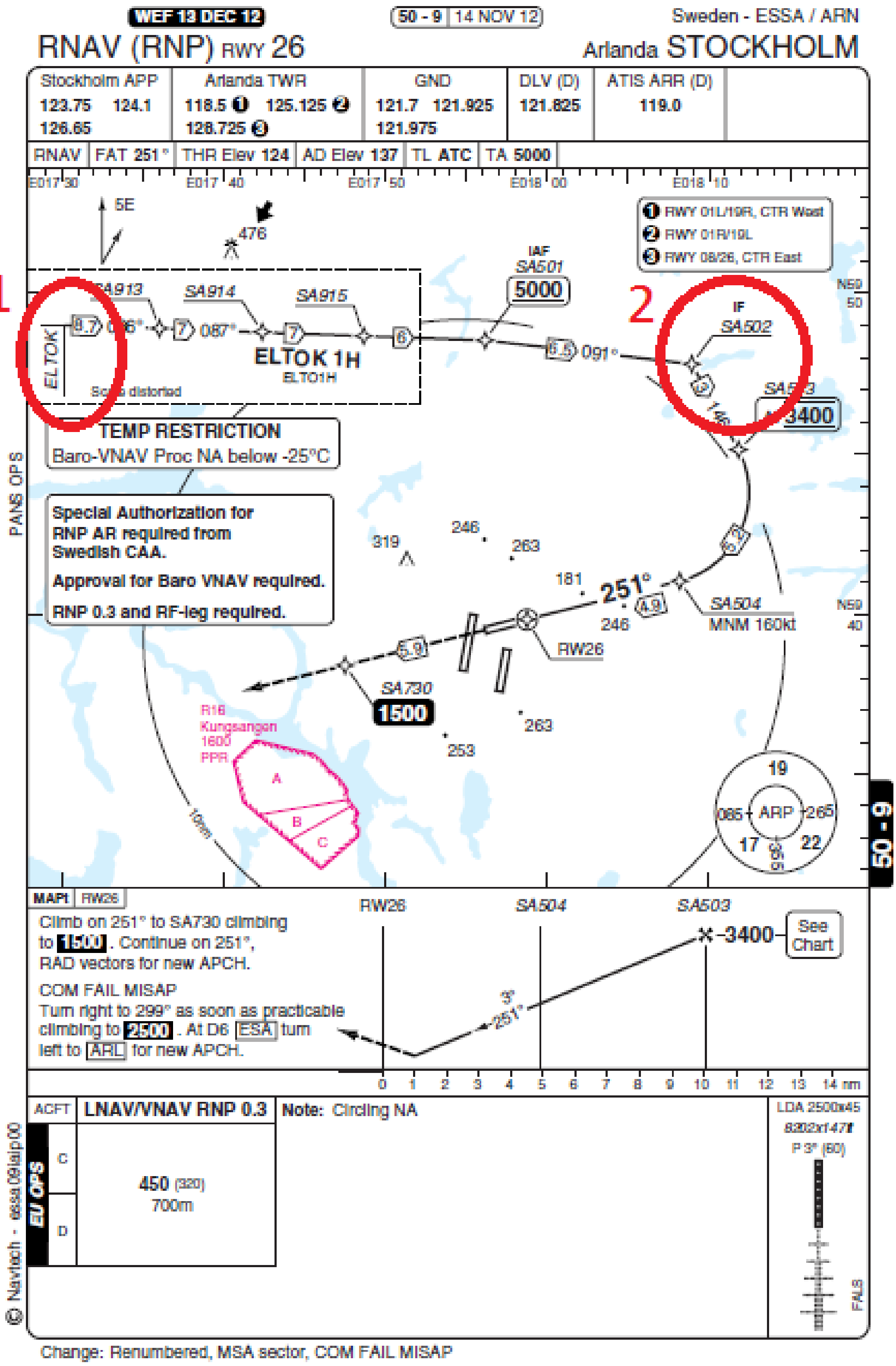


Figure 15: RNP AR procedure, Runway 26 at ARN

Airline behaviour

If several airlines participate in the trial it is necessary to consider any differences in the way they operate. Examples of such factors are:

- Cost Index-Speed
- Standard Operating Procedures (SOPs)
- Wind availability (nowcast-forecast) in the FMS

It is also important to highlight the fact each unique airline involved in flight trials needs to operate the aircraft in a similar way during the reference flights and the trial flights, otherwise this needs to be accounted for. An example of change in behaviour that needs to be compensated for is if an airline aggressively changes its SOP in-between flying the reference flights and trial flights or if the Cost Index used by the airline is changed.

D.6.3 ATC effects

Consider the effect of ATC interventions (radar vectors etc.)

D.7 Choosing which part of the flight to include in the analysis

D.7.1 General

Which part of the flight trajectory to include in the analysis should be selected with great care. It is advisable to exclude the parts that are not affected by the change you are trying to assess. In doing so, you will eliminate a lot of factors that affect the fuel consumption (and thereby the results) but that have nothing to do with the change itself. If those parts are not eliminated, these factors need to be handled which is more complicated than removing them. E.g. when performing a fuel efficiency assessment of two different approach procedures, consider eliminating the taxi, take-off, climb and most of the cruise segment.

However, a procedure change can have positive effects in one phase of the flight while having negative effects on another phase. The total effect must be considered and this means that a large enough part of the flight must be included in the analysis to cover all phases that the procedure affects. E.g. zooming in on a small segment of an approach and assessing the fuel efficiency difference on this short segment is usually unwise. There may be effects on the earlier segments of the approach that might not be obvious. Another example is linked to the departure phase: improved fuel efficiency inside the ICAO-defined LTO cycle (< 3000 ft) can be obtained by introducing noise abatement procedures which have the high-level objective of mitigating noise close to the airport. However the overall fuel burn is adversely affected by this initiative, since the aircraft is flown for a prolonged period of time with low speed in a high drag configuration and this will adversely affect the flight efficiency for a given reference distance.

Comparisons must be based on similar changes in energy state or the difference must be corrected for. E.g. an aircraft entering the measuring zone with a true airspeed of 300 knots and at an altitude of 9000 feet has much higher energy than another aircraft entering the same scenario with a true airspeed of 250 knots and at an altitude of 7000 feet. If assessing the fuel efficiency of different approach procedures, consider stopping the measurement at a suitable point in the final approach in order to remove the effects of pilot handling and of wind on the geometrical segment on the final approach.

D.7.2 Departure

When assessing fuel efficiency of departure procedures, the comparison must consider not only the fuel used to a certain distance from the airport (always after Top of Climb (TOC)), but also the remaining distance to the destination after the points where procedures are compared. This is illustrated in Figure 16.

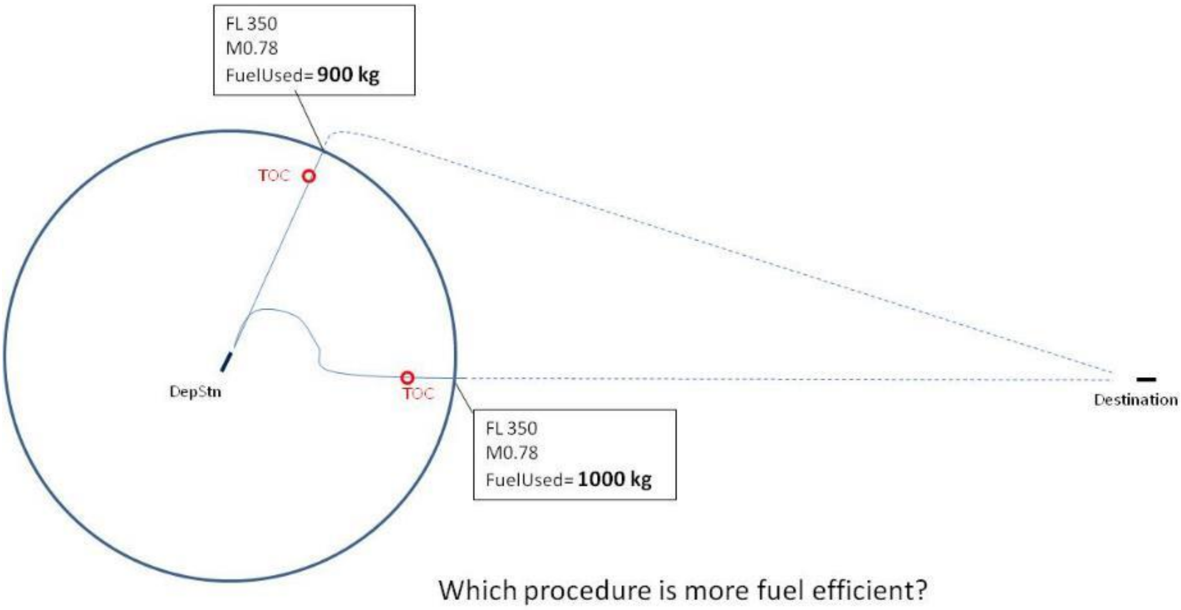


Figure 16: Fuel usage during departure

D.7.3 En-route

Flight path shortenings measured as ground distance cannot always be directly translated into fuel savings. A shorter track can take the flight into a less optimum wind scenario. Thus air distance is a better measure for track shortenings – at least for longer flight path shortenings. Furthermore, if the shorter track can only be achieved at less optimum cruise levels, the fuel improvement will be impaired. A flight including a step climb cannot be directly compared with a flight at constant cruise level. Thus, it may be necessary to also consider vertical profiles. For these reasons it may be better to measure fuel burn rather than track mile savings.

D.7.4 Arrival

When assessing the fuel efficiency of different arrival procedures, the comparison needs to start, at the latest, from the point in the flight where the vertical profile of the two procedures to be compared start to diverge from each other (i.e. at the top of descent of the flight initiating its descent first).

Total fuel efficiency difference

Measuring the fuel consumption(at the latest) from the point where the flight profiles of the two procedures start diverging and comparing this between the reference flights and trial flights will result in the total fuel efficiency difference between the two procedures; i.e. both horizontal (track mile difference) and vertical (level offs etc.) efficiency differences.

One way of doing this can be to start measuring from a given radius from the destination aerodrome, large enough to ensure that no flight has yet started descending towards the destination airport. Using the delta burn methodology, the fuel consumption from this point up to the landing point for the actual flights (the blue line in Figure 17) is compared to the fuel consumption of the theoretically optimum flight (the green line in Figure 17). Once this is done for all flights, the deltas in fuel burn are compared. The distance travelled from the starting point of the measurement to the landing point by the actual flight (the blue line) will be longer than the theoretically optimum flight (the green line) unless the actual flight is perfectly straight in the approach procedure from the radius up to landing. This is how both the horizontal and vertical aspects are covered by this method.

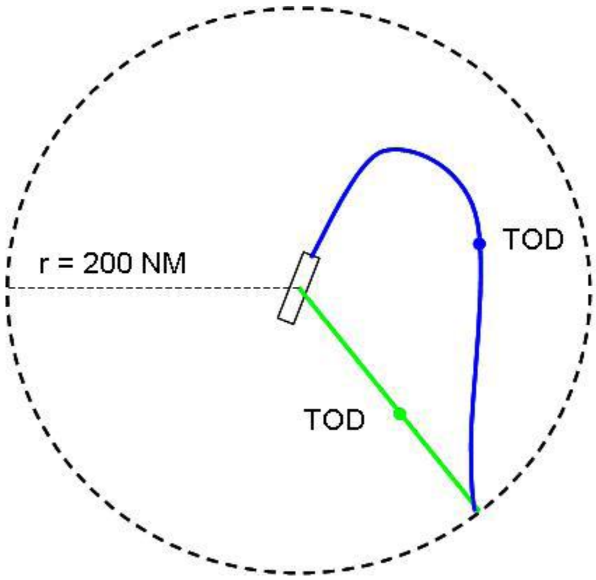


Figure 17: Measuring fuel burn from a given radius

Vertical fuel efficiency difference

To assess the vertical efficiency difference between two arrival procedures, the measurement must start from the point on the different arrival procedures where the flights to be compared have the same distance to go until touch down (but still before the flight profiles start diverging vertically).

One way of doing this, using the delta burn methodology is to calculate distance to go in the flight recorder data by starting at the landing point and calculating backwards using ground speed and elapsed time. Once this extra column has been created in the flight recorder data it is easy to start measuring the fuel consumption from the point where the flights have the same distance to go. The fuel consumption of the actual flight is then compared with the fuel consumption of the theoretically optimum flight from the point where these flights have the same distance to go. In Figure 18, the actual flight is represented by the blue line and the theoretically optimum flight by the green line. Note that they both have 200 NM to go from the point where the fuel consumption is measured from.

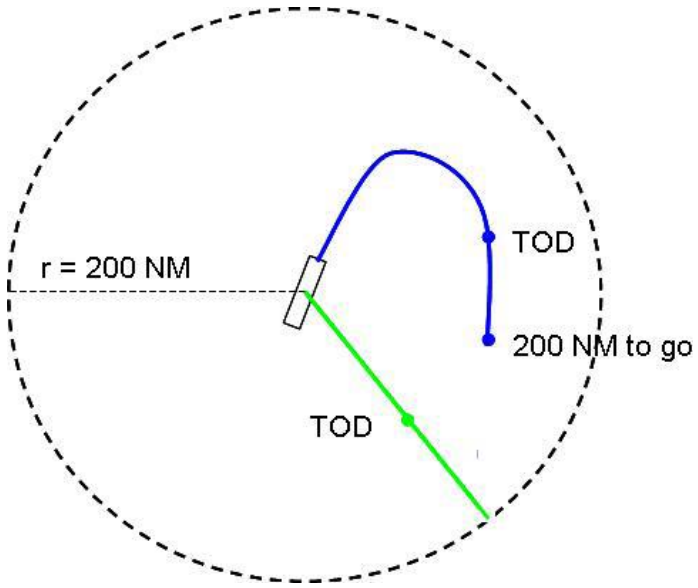


Figure 18: Measuring the fuel burn from for the same distance to go

Horizontal fuel efficiency difference

Having calculated the total fuel efficiency difference and the vertical fuel efficiency difference, the horizontal fuel efficiency difference can be calculated by subtracting the latter from the former.

Examples of arrival cases

In this section a number of examples are given illustrating the need to include the proper part of the flight trajectory in order to obtain the correct results.

Figure 19 illustrates the importance of staring the measurement at the latest at the point where the flight profiles start diverging. Two flight profiles are plotted; “the red flight” and “the green flight”. The red flight has a level-off segment at low altitude. The green flight does not have this low-altitude level-off segment but instead has a significantly longer level-off at a higher altitude. The longer level-off segment causes the top of descent of the green flight to be situated earlier than that of the red flight. Looking at the whole scenario from point A to point C it is obvious that the red flight is more efficient than the green flight. However, if only the segment between point B and point C is assessed, the green flight appears to be more efficient than the red flight. Consequently, to get the correct values for the fuel efficiency difference between the two procedures, the assessment must include the segment from point A to point C.

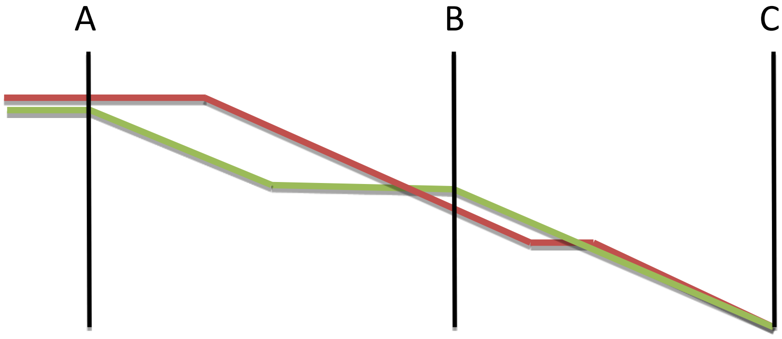


Figure 19: Two different descent profiles

Another example for the descent phase is illustrated in Figure 20. Again we have two flight profiles following two different flight procedures: the “red flight” and the “green flight”. The red flight follows a longer flight procedure than the green flight (illustrated by the red flight reaching ground level later than the green flight, at point E instead of at point D). The red flight also has a level-off segment during the descent while the green flight does not. Suppose we wished to assess the fuel efficiency difference between the two procedures by comparing the fuel consumption from point C to landing.

Both flight procedures pass the geographical point C, but the red procedure has a longer distance to go after that point than the green procedure. Hence, the green flight starts descending earlier than the red flight and will be at a lower altitude than the red flight when passing point C.

By adopting this method, the result will be incorrect and will disadvantage the shorter green procedure. The flight profiles of the two procedures start diverging at point A where the green flight starts descending. In the segment A to C (which is not included in the calculation in our incorrect method in this example) the fuel consumption of the red flight will be considerably higher than the fuel consumption of the green flight since it is in cruise phase for part of the segment while the green flight is descending with its engines at idle thrust. The segment D to E (which is included in the calculation in our example) partly covers the fact that the red procedure is longer by calculating the fuel consumption for a longer period of time for the red flight than for the green flight during descent. But this does not take into account the fact that in the segment between point A and point B, the red flight was in cruise phase with a higher fuel flow than between point D and E. To obtain a result that includes the total efficiency difference between the two flight procedures, the measurements must start at the latest at point A. Starting earlier is not a problem since both flights then will be in cruise.

To summarise: The energy state (potential and kinetic energy if the aircraft is seen as a point mass) of the flights that are being compared needs to be equivalent at the start of measurement.

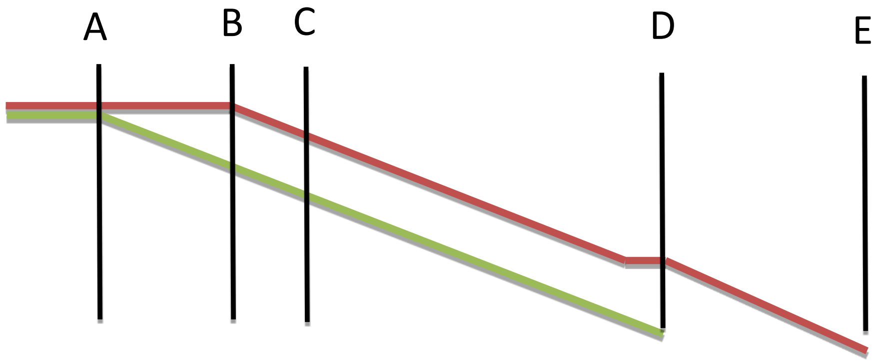


Figure 20: Different measurement points associated with two flight profiles

An example illustrating the importance of comparing the same distance travelled when assessing vertical fuel efficiency is shown in Figure 21.

Suppose we would like to assess the vertical fuel efficiency of the two flights (the “red flight” and the “green flight”) from 6000 feet to landing. The green flight leaves its cruising level at the optimum top of descent and conducts a descent with idle thrust from point A to point D. At the same time, for some reason (traffic or other) the red flight is forced to stay on its cruising level for a considerable time after passing the optimum top of descent. This will generate a scenario where the aircraft is above it optimal vertical profile. To re-intercept its intended trajectory, the aircraft needs to fly with higher speed (if possible) and using speed brakes to dissipate excessive energy.

If we start measuring fuel consumption from the point where the flights pass 6000 feet (point B for the green flight and point C for the red flight) the fuel consumption of the red flight will be lower than the fuel consumption of the green flight since it descends faster and passes 6000 feet closer to the airport than the green flight.

Not taking the distance travelled into account, the red flight incorrectly appears to be more fuel-efficient than the green one. Setting the fuel consumption in relation to the distance travelled will, however, correctly indicate that the green flight is more efficient than the red one. If the measurement started at the point where the two flight profiles start to diverge from each other (point A), the assessment would also have been correct since the longer cruise segment of the red flight would have outweighed its shorter descent compared with the green flight.

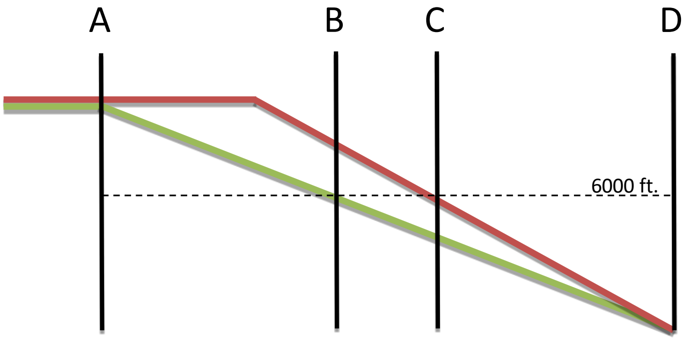


Figure 21: Low drag descent vs. high drag descent

D.8 Considering the total effect

Once the fuel saving due to an operational change has been assessed, the total effect of the saving can be considered. In some cases, the total effect can be higher than the fuel saving itself due to the operational improvement. E.g. if a procedure is implemented which results in lower fuel consumption and this is something you can take into account at the flight planning stage, less fuel needs to be carried. This in turn results in a lower fuel consumption of the flight due to a lower mass of the aircraft - the longer the flight, the higher the saving.

Another effect, that might be harder to assess though, is that if a new procedure is implemented that the pilots feel more confident with, they might bring less extra fuel.

Looking at a purely economic aspect, reduced engine wear due to a shorter procedure (or lower aircraft mass) is something that can be taken into account.

If any additional factors such as the above are taken into account when communicating the results, on top of the absolute saving assessed, it must be clearly stated what is included and which assumptions are made!

D.8.1 Assessing the confidence of the results

Once the results have been obtained, a critical review of their reasonableness from an operational viewpoint is paramount. Are the results in line with what can be expected based on the implemented change?

In addition to this, an assessment of the significance of the results from a statistical viewpoint should be performed.

When communicating the results, only communicating an average value has its limitations and one also needs to look at a confidence interval for this average. This confidence interval is centred on the observed average and its width depends on the number of flights included in the analysis, on the dispersion of the figures making up the average and on the level of confidence for this average. Once a confidence interval has been determined for the trial observations and one has been calculated for the measurements that are used as reference, these two will be compared in place of comparing the average values only. If these two intervals do not overlap, the result of the trials will be significantly different from that of the reference observations with a high probability (95% if you have used 95% confidence intervals). Such a process adds strength to your conclusion.

Using a lower confidence level reduces the width of the confidence intervals: it is thus easier to get intervals that do not overlap but the strength of your conclusion will be lowered (e.g. using 80% instead of 95%).

D.8.2 Calculating a confidence interval

In order to calculate the confidence interval for the average of a given sample of measurements, the following formula can be used, based on using the Microsoft Excel® program. This method is theoretically valid from a minimum number of observations (flights) of 50 for both samples to be compared (50 reference flights and 50 trial flights).

- Confidence intervalmin = mean – TINV(probability, n-1)*stderr
- Confidence intervalmax = mean + TINV(probability, n-1)*stderr

Where:

- mean is calculated using the Excel formula AVERAGE(),
- TINV is an Excel function (for calculating the two-tailed inverse of the Student's t-distribution),
- probability is given as 1-(confidence level for the confidence interval). It is a value between 0 and 1, e.g. 95% probability is given as 1-0,95 = 0,05,
- n = size of sample,
- stderr = standard deviation of the sample - square root of size of sample.

Figure 22 illustrates a screenshot from Excel, displaying the calculations for scenario 4 described below. There are 100 trial flights and 100 reference flights and the probability is set for a 95% confidence interval.

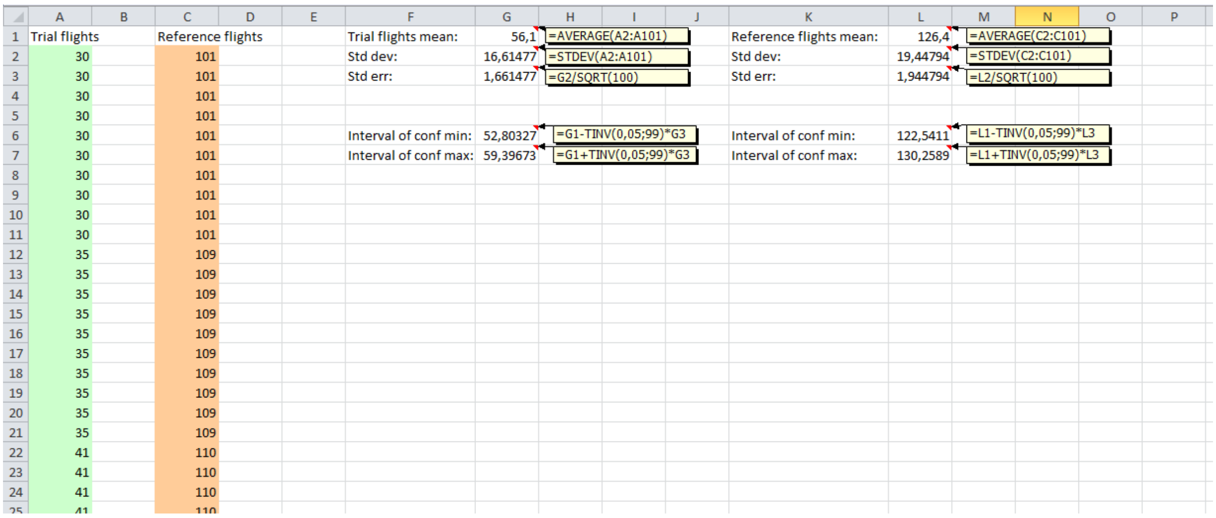


Figure 22: Example of using Excel for statistical analysis

To illustrate the concept, we will now look at four different fictive flight trial results. In these examples we have used the delta burn methodology for analysing the flight trials. Hence a delta burn has been calculated for each individual flight, giving the number of kilograms of fuel each actual flight was above the theoretically optimum under the same conditions. The following four scenarios (S1-S4) are used:

- S1: A flight trial based on 10 trial flights and 10 reference flights. The dataset has quite a large variation in delta burn.
- S2: A flight trial based on 50 trial flights and 50 reference flights. The dataset has quite a large variation in delta burn.
- S3: A flight trial based on 100 trial flights and 100 reference flights. The dataset has quite a large variation in delta burn.
- S4: A flight trial based on 100 trial flights and 100 reference flights. The dataset has a smaller variation in delta burn compared with the three previous scenarios.

The following table illustrates details for each scenario. Below the table is an explanation of each column.

	Trial flights				Reference flights			
	Std dev	Std err	Avg delta burn	Avg delta burn confidence interval	Std dev	Std err	Avg delta burn	Avg delta burn confidence interval
S1	47	15	84 kg	50-117 kg	49	15	162 kg	127-197 kg
S2	45	6	84 kg	71-96 kg	47	7	162 kg	148-175 kg
S3	45	5	84 kg	75-93 kg	47	5	162 kg	152-171 kg
S4	17	2	56 kg	53-59 kg	19	2	126 kg	123-130 kg

Std dev = Standard deviation of the deltas
Std err = Standard error in the average delta burn
Avg delta burn = Average delta burn for all flights in the specific group (trial flights or reference flights)
Avg delta burn confidence interval =The 95% confidence interval calculated for the average delta burn of all flights in the specific group (trial flights or reference flights)

As can be seen in the table above, there are two factors affecting the confidence interval:

- The number of measurements within the dataset (number of flights)
- The dispersion of the measurements in the dataset (which is represented by the standard deviation)

The larger and the more homogenous dataset you have, the narrower the confidence interval will be (and hence the higher the reliability of the results). Scenario 1 has only 10 flights and quite a large dispersion in the delta burn for these flights. As can be seen, the confidence interval for this group is considerably larger than the confidence interval for scenario 4, which is based on a larger and more homogenous dataset.

D.9 Dos and Don'ts

To summarise, performing a fuel efficiency assessment of flight trials is a challenging task. A lot of factors influence the fuel consumption of a flight and when evaluating the results of flight trials, often a relatively small effect needs to be identified against the background of normal variance. The following are the recommendations given in this appendix in a short bullet form.

- Base the analysis on the most accurate data source available (preferably flight recorder data);
- Make sure to handle any anomalies in the flight recorder data in order for these not to erroneously affect the results;
- Choose the reference and trial flight datasets with care. The more similar the two datasets are the fewer factors might need to be compensated for in order to identify the fuel efficiency difference correlated to the change to be assessed;
- Include as many flights as possible in the reference and trial datasets;
- Preferably set up the trial and choose the datasets so that only one operational improvement is assessed at a time (and differ between the two datasets);
- Beware of trial flights being treated as "royal flights";
- Handle as many of the parameters affecting the fuel consumption of the flights as possible before comparing fuel burn (either through using the delta burn method or by normalising using mathematical formulas);
- Ensure that the behaviour of the participating airlines is comparable and also ensure that the individual airline behaviour is the same for both the reference and trial flights. If not, this needs to be corrected for;
- Never compare planned versus actual outcome (e.g. fuel consumption according to flight plan versus actual fuel consumption) but always planned versus planned or actual outcome versus actual outcome.
- Choose which part of the trajectory to include in the analysis carefully. Exclude the parts that are not affected by the change in order to remove unwanted influence while at the same time including a sufficient part of the trajectory to cover all phases that the procedure change affects;
- Make sure that compared flight scenarios are based on a similar change in energy state, or this must be corrected for;
- When assessing departures:
    - The comparison must consider not only the fuel used to a certain distance from the airport (always after Top of Climb) but to the first common point.
- When assessing the en-route phase:
    - Consider air distance rather than ground distance when assessing track shortening;
    - Consider the vertical aspects (step climbs and optimum altitudes) as well.
- When assessing arrivals:

  - Consider stopping the measurement at a suitable point in the final approach in order to remove the effects of pilot handling and of wind on the geometrical segment on the final approach;
  - When assessing the fuel efficiency of different arrival procedures, the comparison needs to start, at the latest, from the point in the flight where the vertical profile of the two procedures to be compared start to diverge from each other (i.e. at the top of descent of the flight initiating its descent first).
- If any additional factors (e.g. the carry factor) are taken into account when communicating the results, on top of the absolute saving assessed, it must be clearly stated what is included and which assumptions they are based on;
- Once the results have been obtained a reality check should be performed. Are the results in line with what can be expected based on the implemented change?
- An assessment of the significance of the results from a statistical viewpoint should also be performed. In doing so, assess the confidence interval of the results;
- Communicating the confidence interval together with the results adds strength to your conclusions.