D5.3 – Use Cases Framework Implementation

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Abstract

This deliverable presents the operating scenarios of three demonstration use cases of the Impact Monitor project, as well as the status of their implementation in the Impact Monitor collaborative assessment framework. A preliminary example of partial execution for each use case is also exposed.

Keywords

Demonstration, Use Cases, Implementation, Framework

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Table of Acronyms and Abbreviations

Acronym/Abbreviation	Description / Meaning
ATS	Air Transport System
BADA	Base of Aircraft Data
CDO	Continuous Descent Operations
CINEA	European Climate, Infrastructure and Environment Executive Agency
CPACS	Common Parametric Aircraft Configuration Schema
CU	Cranfield University
DLR	Deutsches Zentrum für Luft- und Raumfahrt e. V. (German Aerospace Center)
EEA	European Economic Area
GA	Grant Agreement
KER	Kerosene
KPI	Key Performance Indicator
MD(A)O	Multi-disciplinary Design (Analysis) Optimization
MDAX	MDAO Workflow Design Accelerator
NLR	Stichting Koninklijk Nederlands Lucht- Ruimtevaartcentrum (Royal Netherlands Aerospace Centre)
OD (pair)	Origin - Destination (pair)
ONERA	Office National d'Etudes et de Recherche Aerospatiales
RCE	Remote Component Environment
R&I	Research & Innovation
SAF	Sustainable Aviation Fuels
TLAR	Top Level Aircraft Requirement
TML	Transport & Mobility Leuven
UC	Use Case
ULR	Ultra Long Range
UHBR	Ultra High Bypass Ratio
VHBR	Very High Bypass Ratio
UPC	Universitat Politècnica de Catalunya (Technical University of Catalonia)
WP	Work Package

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XDSM	eXtended Design Structure Matrix
XML	Extensible Markup Language
XSD	XML Schema Definition
XWB	eXtra Wide Body

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1. INTRODUCTION

The main objective of the Impact Monitor project is to deliver a coherent and holistic framework and toolbox that aim to become the reference choice for technology and policy assessment of the environmental, economic and societal impact of European aviation R&I. The comprehensive Impact Monitor framework is composed of two tightly connected elements:

- A scalable, open source, distributed and multidisciplinary MBSE framework dedicated to collaborative assessment;
- A web-based environment employed at the post-processing stage for design space exploration and studies analysis;

Within this project, Work Package (WP) 5 develops three example Use Cases (UCs) that aim to demonstrate the capability of the Impact Monitor framework.

Figure 1-1 provides an overview of the work-breakdown structure of the Impact Monitor project with a focus on the interaction between the WPs 3 to 5, which focus on the technical development and implementation.

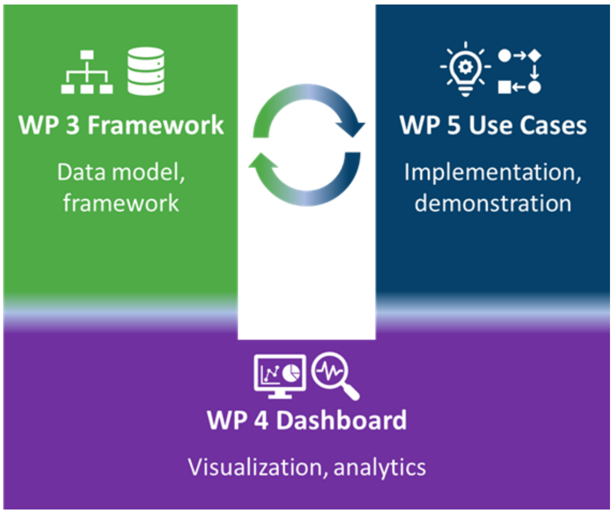

Figure 1-1: Impact Monitor Work-breakdown Structure for Technical Development and Implementation.

More specifically, every UC targets an environmental-, economic- and/or societal- impact assessment of an exemplary (although hypothetical) R&I innovation in aviation; and covers one or more assessment levels (i.e., aircraft, airport and/or air-transport system level). Every UC will be implemented in the Impact Monitor framework developed in WP3 and its results will be accessed through the Impact Monitor Dashboard Application from WP4.

The implementation of the three demonstration UCs follows four steps, from scenario definition to models' selection, which are then integrated into collaborative workflows in order to compute and provide the desired metrics for the quantitative assessment of each defined scenario. Figure 1-2 illustrates the sequence of these implementation steps, which are carried out by all three demonstration UCs.

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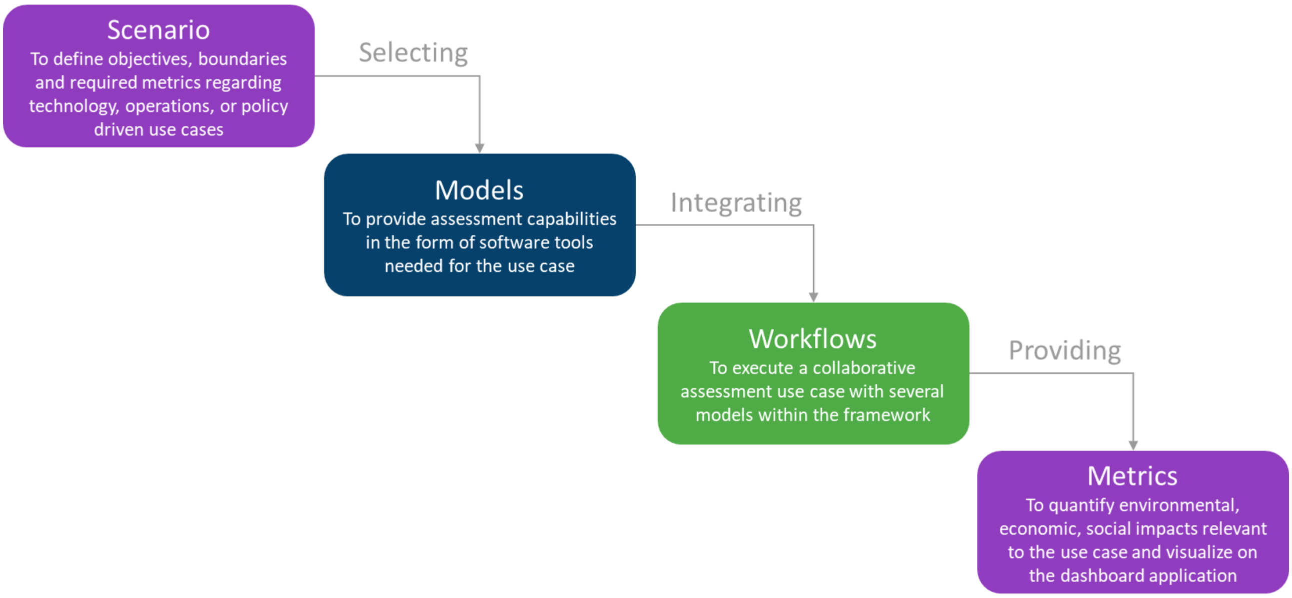

Figure 1-2: Implementation Steps for the Demonstration Use Cases

Jointly, the three UCs address all three assessment levels. Furthermore, these UCs intend to consider expected needs of selected stakeholders as identified in WP2, and to validate the key performance indicators (KPIs) identified in WP1.

The three UCs, together with their respective assessment levels, are shown in Figure 1-3 and are titled as follows:

- UC1: Advanced Propulsion System;
- UC2: Continuous Descent Operations;
- UC3: Sustainable Aviation Fuel.

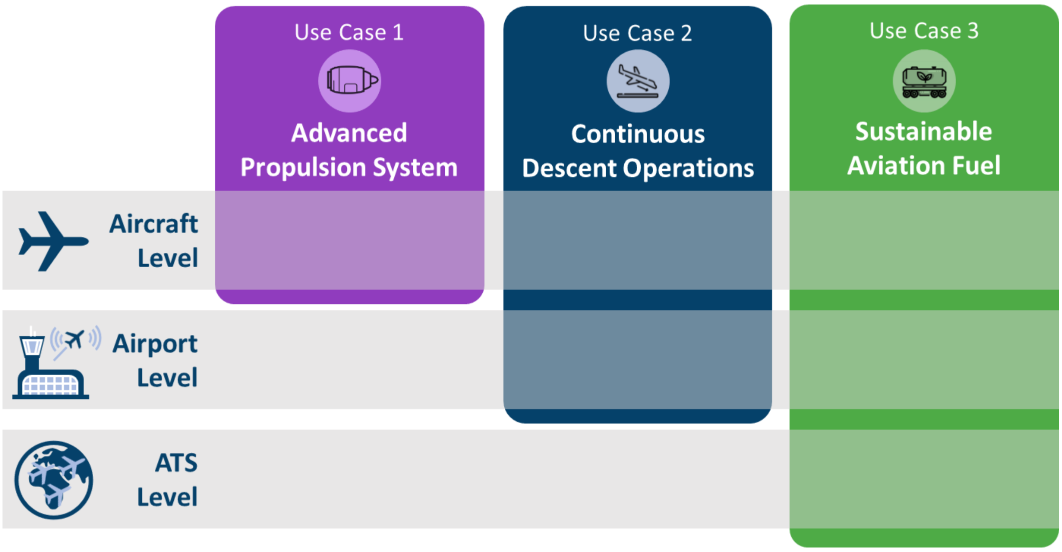

Figure 1-3: Schematic Representation of the Demonstration Use Cases and Assessment Levels

The present deliverable (D5.3) provides the implementation process of the three UCs, including a preliminary demonstration. It is organised as follows:

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- Section 2 describes the different steps of the implementation processes in the Collaborative framework
- Section 3 provides a description of the operating scenarios, of the implementation process and an example of partial workflow execution of UC1 (Advanced Propulsion System)
- Section 4 provides a description of the operating scenarios, of the implementation process and an example of partial workflow execution of UC2 (Continuous Descent Operations);
- Section 5 provides a description of the operating scenarios, of the implementation process and an example of partial workflow execution of UC3 (Sustainable aviation fuel);
- Section 6 concludes the document, summarising the information provided herein.

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2. Technical Implementation

The technical implementation of the UCs is based on the CPACS Design Framework, i.e. a common data schema is used, on the basis of which the design and analysis processes are modelled using MDAx and finally executed remotely via the RCE execution platform. These three aspects are discussed in more detail below.

2.1 Common Data Schema

2.1.1 Introduction to CPACS

The Common Parametric Aircraft Configuration Schema (CPACS) serves as the central data interface for the project partners [1]. CPACS is implemented in Extensible Markup Language (XML) using XML Schema Definition (XSD) to model the actual data structure.

The data model follows an explicit approach in which a clear and comprehensible parameterization of air transport systems is achieved via descriptive element and its properties. From the historical context, CPACS already provides a detailed description of aircrafts and their detailed description at component level. For the Impact Monitor project, CPACS was adapted and expanded at airport and ATS level in line with the project requirements.

Before discussing these extensions in more detail, a brief insight into the data structure and its visualization is provided here. The root node is always <cpacs> (see Figure 2-1). Its child elements are displayed in a top-down tree view. Elements with a solid border occur at least once, but not more than once (i.e., [min..max] = [1..1], i.e. they are mandatory elements. Dashed elements do not need to be specified (e.g., [0..1]). Elements in stacked form indicate that they can be listed more than once (e.g., [1..inf]). In addition, elements on the same hierarchy level are preceded by a symbol that indicates the order of the elements. For example, three contiguous dots represent the so-called xsd:all statement, in which the order of the subsequent elements is arbitrary. On the other hand, three dots next to each other indicate that the order of the elements is mandatory. A switch-like symbol indicates that a selection of subsequent elements must be made, i.e. several elements may not be listed at the same time.

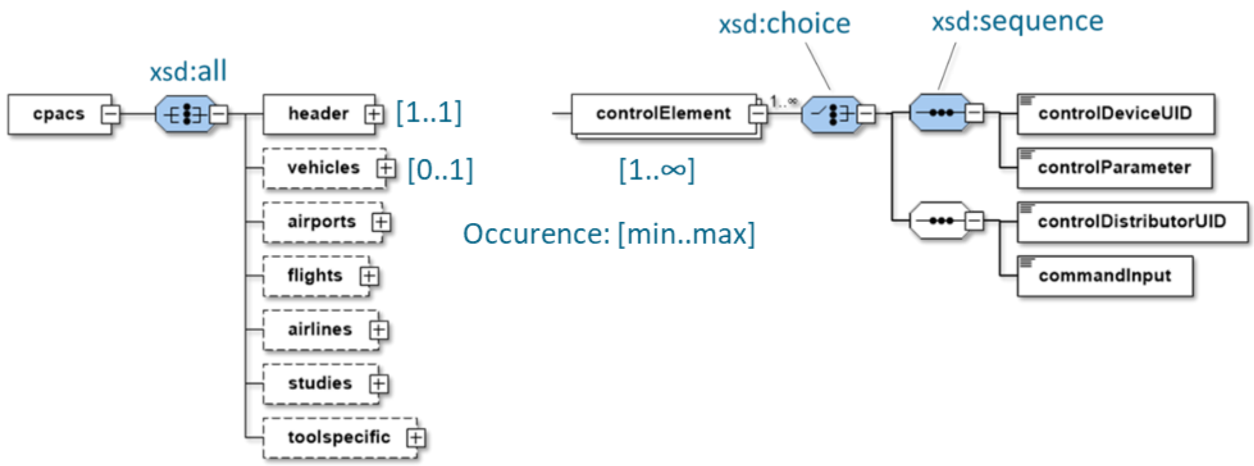

Figure 2-1: Description of XSD diagram symbols

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When CPACS is used in projects, it is common practice to first agree on an official release as a basis and then implement project-specific extensions based on this. This allows projects to make and test changes to CPACS more flexibly without affecting the entire CPACS community in their work with the schema. At the end of such a project, the changes that are found to be good are transferred to the official CPACS development platform. This has also been the procedure in Impact Monitor, with CPACS v3.4 being chosen as the basis. This starting point is shown in Figure 2-2 as an XSD diagram. It can be seen here that CPACS contains an <aircraft> node, which represents the actual vehicle instance. Reusable objects (e.g. engines, material data, cabin components, etc.) can be predefined as vehicle independent library elements. The vehicle-specific geometry is supplemented by a <global> and <analyses> node, which represent high-level information about the aircraft (e.g. number of passengers) and detailed analysis results (trajectory simulations).

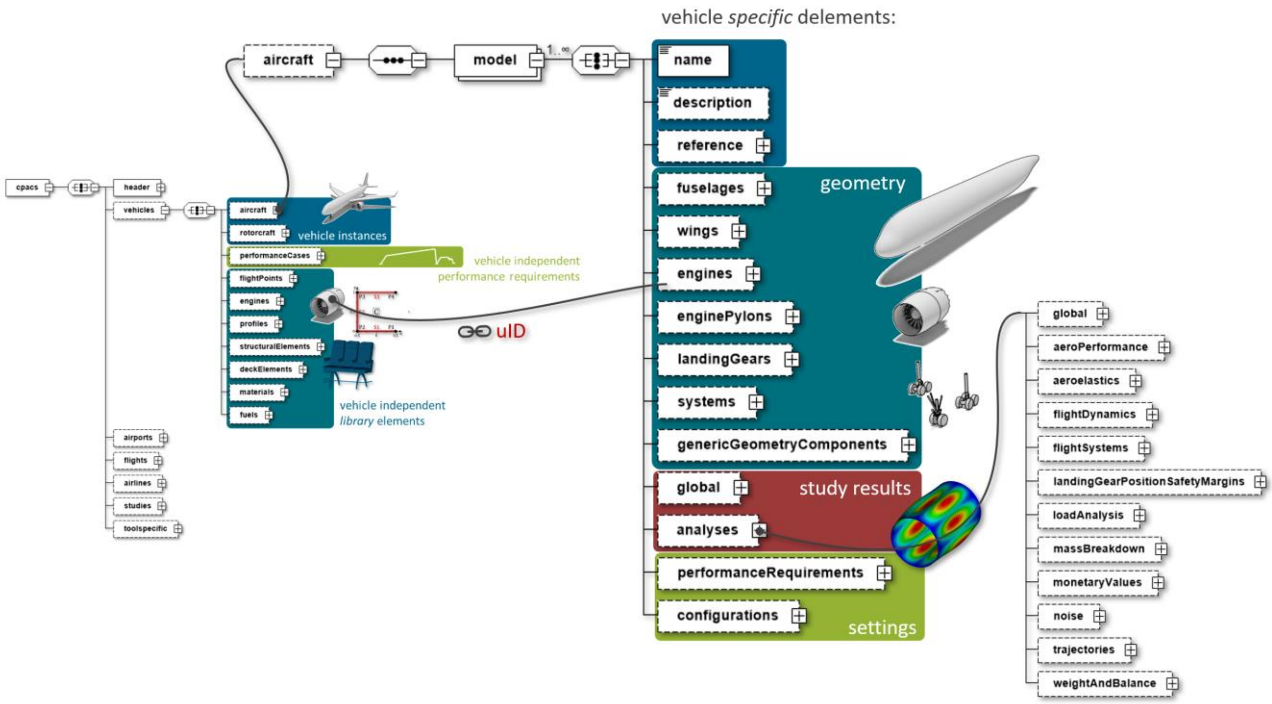

Figure 2-2: Data structure of CPACS v3.4 serving as a base for the project specific schema

Based on this data structure, extensions are implemented in XSD for the Impact Monitor UCs, particularly at the top hierarchy level, which are described in more detail in the following chapters.

2.1.2 Connection of tools to CPACS

The XML library TiXI was used to integrate the analysis modules of the project partners in Impact Monitor into the framework. This is a C implementation of libxml2 with some CPACS-specific additions, which provides bindings for various programming languages (e.g. Python, Matlab, Fortran) [2].

Using TiXI as an example, a dummy tool was provided in Python, which demonstrates an exemplary connection to the data model to the project partners. Each tool then implemented a pre- and post-processing part that can read in a generic CPACS file, add basic provenance information to the <header> node (e.g. <description>, <creator>, <timeStamp>) and write this information out as a

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new CPACS file. This comprehensively covers the technical requirements that are necessary for connecting tools to CPACS.

2.2 Collaborative Workflow Development

The design and analysis processes (hereafter referred to as workflows) for the three different UCs in Impact Monitor are defined in a first step using the eXtended Design Structure Matrix (XDSM). For this purpose, the DLR software MDAO Workflow Design Accelerator (MDAx) is used. This enables workflow integrators and tool developers to define the required inputs and outputs via a web-based graphical user interface (see Figure 2-3). MDAx then determines the optimum sequence of tools in the workflow by automatically linking these inputs and outputs. In addition, class MDAO elements such as convergers, design of experiment drivers and optimizers can be added. Finally, the modelled workflows can be exported to an executing integration platform such as RCE (see Sec. Remote Workflow Execution2.3).

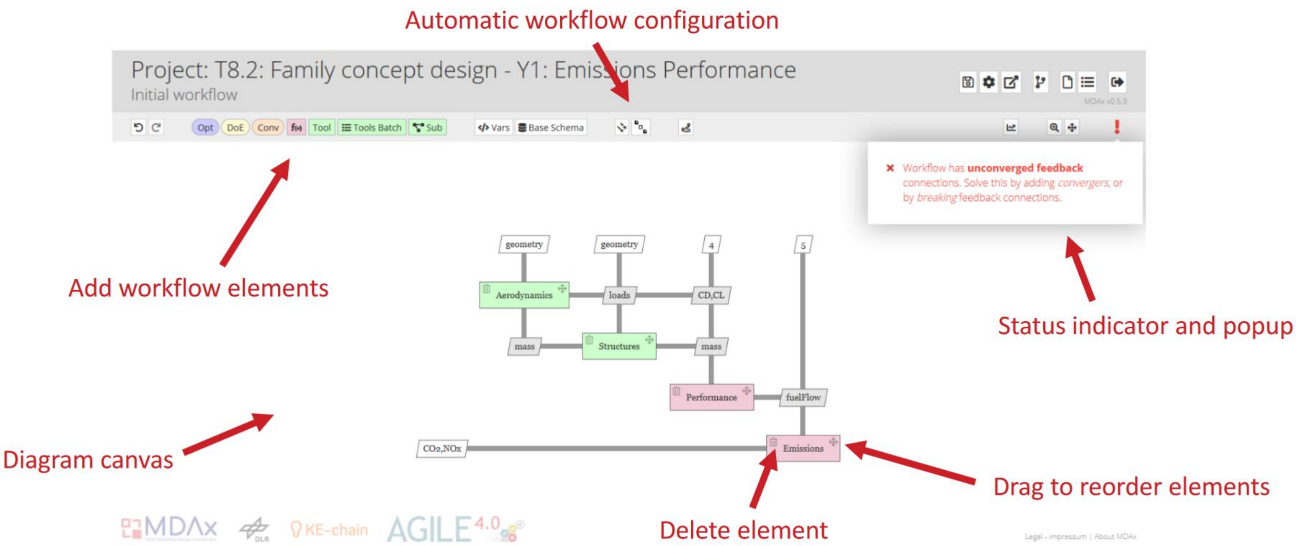

Figure 2-3: Graphical user interface of MDAx for an example MDAO problem [3]

As a first step, the tool developers were asked about their required inputs and outputs at regular UC-specific meetings. These could be defined in MDAx as freely definable but hierarchically arranged elements so as not to distract participants directly with details of the CPACS data model at the start of the implementation phase. As a result, the missing inputs or outputs can be easily identified and corresponding resource planning can be carried out in the project (e.g. which tool could supply the required data, are external databases available, is output data even required in the workflow, etc.).

In a subsequent step, the inputs and outputs are mapped to the CPACS data structure. This makes it possible to identify where the data model needs to be modified or extended. In an iterative process, the project-specific CPACS data model can be imported into MDAx and the mapping of inputs and outputs adjusted until all required data transfers are correctly mapped in an overall workflow.

Finally, it should be emphasized that the workflow development process can be carried out independently of the technical connection of the tools to CPACS and the implementation in RCE. This allows efficient parallelization of the work in the Impact Monitor project.

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2.3 Remote Workflow Execution

The Remote Component Environment (RCE), developed at DLR, is used as distributed integration platform for the implementation and remote execution of the workflows [4].

2.3.1 Local integration of tools into CPACS

Based on a tutorial which was provided to the project team, each tool was locally integrated into RCE based on the previous CPACS connection described in this section. For this step, the input CPACS file is not provided by manually copying it to the tool's input directory, but via the RCE input provider. Similarly, the output is passed to the RCE output provider. Once this integration task has been successfully completed, the tools are technically ready for integration into workflows.

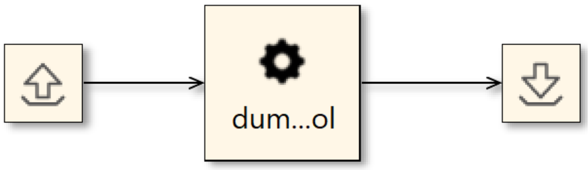

Figure 2-4: Local integration of a dummy tool into RCE

2.3.2 Establishing remote connections via Uplink and Brics

The final step is to make the tools integrated locally in RCE available for remote execution in a network. One of the two techniques used in the Impact Monitor project is the so-called Uplink feature of RCE. Uplink is an experimental feature introduced in RCE 10.x that addresses the growing need for the exchange of computation services between different organizations. Conceptually, this is realized using RCE's standard approach of providing access to local tools as distributed services, while keeping the tool's files and execution on the local machine. The Uplink approach addresses IT security issues by providing a shared coordination and forwarding server called a "relay". This relay server is typically placed outside of any organization's protected network, e.g. on a rented server or in the DMZ of one of the involved organizations. Connections are established via an encrypted and authenticated SSH protocol [5].

DLR set up an uplink server for Impact Monitor and made it available to all project partners for the entire duration of the project. The partners apply for individual accounts in order to connect to the uplink network via a user name and password. As a second level of security, so-called access groups are defined, which enable the individual provision of their tools only for the project and, if necessary, restrict the availability of the tools to the individual UCs. Once these steps have been successfully completed, the local RCE instance is connected to the network and external tools of the project partners are available in the tool palette, identical to the locally integrated tools (see Figure 2-5). Project partners can disconnect or close their RCE client to prevent the unintended execution of their tools.

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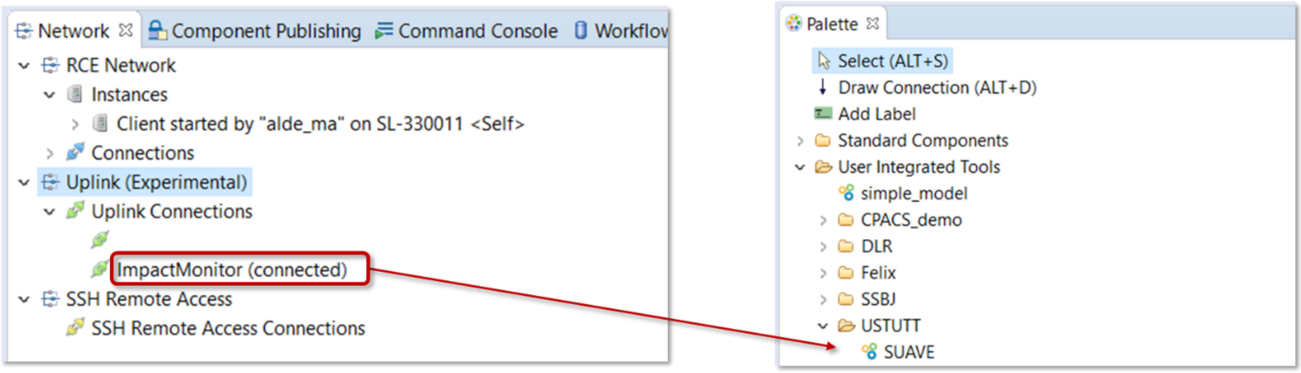

Figure 2-5: Example of RCE instance connected to RCE Uplink – a DLR client can access a tool from University of Stuttgart.

The other technique used in the Impact Monitor project to integrate local tools and RCE workflows that are distributed across several organisations into a cross-organisation collaborative workflow is employing the Brics technology [6] - [7].

Local RCE workflows may be equipped with Brics building blocks that facilitate the composition and execution of collaborative workflows across organizational borders in a service-oriented architecture style, while complying with the applicable security constraints and dealing with the security measures of the collaborating partners. Brics provides generic protocols and middleware that can easily be used standalone as well as integrated in any workflow management tool, such as RCE. The middleware orchestrates execution and data exchange across workflows and services that constitute the collaborative workflow, thereby obeying the ICT security measures of the organizations involved and enabling the respective specialists and organisations to remain in full control of their own tools, data and other resources being accessed. To facilitate the secure exchange of data among organizations involved in the execution of a collaborative workflow, the DLR TeamSite is used in the Impact Monitor project.

Brics facilitates the use of stubs in local workflows for calling remote tools and workflows; cf. Figure 2-6. In the Impact Monitor project, a stub is a small RCE tool (which calls a script that in turn uses Brics) that provides the local workflow with the same interface of the remote tool or workflow in terms of accepting the same inputs and producing the same outputs. Internally, however, the stub uses the Brics middleware to "call" a remote tool or workflow, thereby taking care of the triggering, the synchronization, and the data transfers involved. Brics also facilitates the creation of services and local workflows that may play the role of remote tool or workflow for a stub. As such, Brics provides the building blocks, which are also RCE tools, for accomplishing a service-oriented setup for distributed collaborative workflows. A local workflow executing a stub temporarily becomes the client (requesting a service). The remote tool or workflow then becomes its server (providing a service). In the context of the Impact Monitor project, scripts are provided that enable inclusion of stubs in client workflows and that enable local workflows to be defined as server workflows.

The basic role of Brics in the service-oriented set-up is depicted in Figure 2-6. The stub (with Brics calls embedded) at the client site is labelled with 'C'. 'D' (from 'download') at the server site identifies the RCE tool (with Brics calls embedded) that handle calls from the stub by downloading the input file and

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providing it as input for the actual tool. 'U' (from 'upload') identifies the RCE tool (with Brics calls embedded) that takes the output from the actual tool and passes it back to the stub. In summary, when the stub is activated, it employs the Brics protocol to accomplish the remote tool execution as if the remote tool was part of the local workflows.

The numbered arrows in Figure 2-6 represent the steps to accomplish the remote execution. First, the input files for the remote service are uploaded to the central data server in a neutral domain, i.e., the DLR TeamSite in the Impact Monitor project (1). Next, the remote specialist gets notified (2), who in response starts the remote service (3). The service retrieves the input files from the data server (4), runs the engineering service (5), and uploads the output files to the data server (6). Finally, the output files are downloaded to the client's side (7), and the client workflow continues execution.

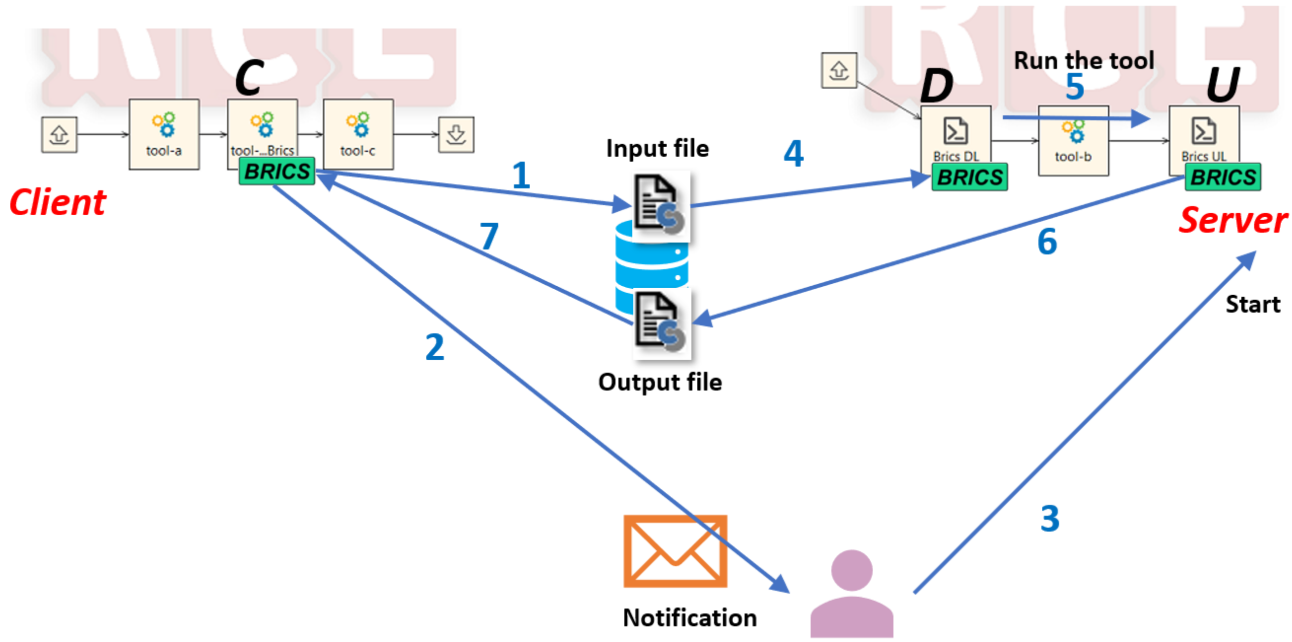

Figure 2-6 Schematic representation of the Brics protocol in the context of a client and a server workflow in RCE. The numbered arrows indicate the steps taken to accomplish the remote execution, as described in the text above.

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3. Use Case 1: Advanced Propulsion System

In Work Package 5, Cranfield University is leading the task on "Technologies on aircraft level and their impacts", while also contributing to the Use Case on 'Advanced Propulsion System' through modelling and simulation of SAF fuelled novel aircraft concepts with advanced propulsion systems. Details of Use Case can be found in upcoming sections.

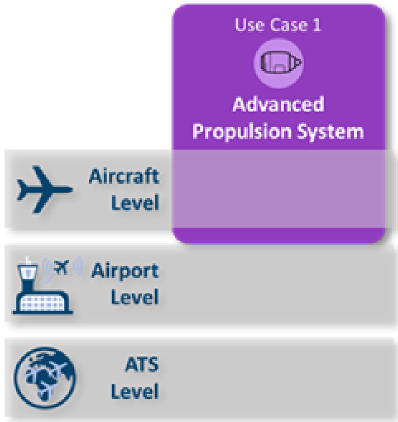

Figure 3-1: Aircraft Level Assessments (Use Case 1)

3.1 Scenario Definition

Primarily an aircraft level analysis, the use case would be focused on investigating the viability and competitiveness of future SAF-fuelled novel aircraft concepts with advanced propulsion systems for long range application (assuming a 2040/50 EIS).

Aircrafts to be used for the analysis and study:

- Conventional Tube and Wing aircraft (Long Range based on A350 XWB – 900 ULR)
- Conventional Tube and Wing aircraft (Short Range based on A321 Neo)

Starting with a set of pre-defined TLARs (Top Level Aircraft Requirements), the novel aircraft architecture design will be based on the above-mentioned aircraft models. To demonstrate the applicability of a family of aircraft, two variants of the concept will be modelled, which will be sized for different payload / seat and range capabilities. The analysis will further entail a performance comparison for typical missions with the SAF fuelled "classical technology" aircraft (adapted from SAF use case) to establish improved payload-range capability & emission reduction potential. A set of metrics such as Aircraft level fuel burn (kg), Aircraft level emissions (CO2) & Energy to revenue work ratio will be applied.

Comparison between 2 propulsion systems:

- VHBR (9-10) – Based on Trent XWB (KER + SAF)
- UHBR 15+ with Gearbox (Based on Trent Ultrafan) (KER + SAF)

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Main Tools involved in use case 1 are shown in Table 1.

Table 1: UC1 tool overview

Tool name	Description	Tool vendor
Turbomatch	Engine Modelling	Cranfield University
SAUVE	Aircraft Conceptual Design Initiator	University of Stuttgart
AECCI	Aircraft Emissions and Contrails for Climate Impact	ONERA
DYNAMO	Trajectory amendment for contrail avoidance	UPC
HAT	Holistic assessment tool towards sustainability	University of Patras/ Cranfield University

As part of evaluating solutions and technologies for reducing the environmental impact of aviation, this use case focused on aircraft level assessment will be analysing several critical performance metrics related to sustainability. The agreed key performance indicators (KPIs) for assessment include fuel burn, carbon dioxide emissions (CO2), nitrogen oxide emissions (NOx), overall sustainability, and contrails.

Compared to the status reported in Deliverable 5.2 [6], the scenario definition has been refined in terms of exploration scope: for each aircraft model designed thanks to the SUAVE/Turbomatch coupling, different combinations of payloads, trajectories, atmospheric conditions, etc. are now studied with DYNAMO and AECCI in order to obtain higher fidelity results.

3.2 Technical Implementation

This section presents the methodology for how Use Case 1 "Advanced Propulsion System" will be implemented and demonstrated. The proposed MDO framework (Impact Monitor Framework, developed in WP3), and the design space exploration environment (Dashboard Application, developed in WP4), will be employed for the execution of this use case. The storyboard for the execution of this use case is presented in Figure 3-2.

First, the user will specify the top-level aircraft requirements (TLARs). Next, the aircraft mission and the configuration/architecture will be modelled. Step 3 of the storyboard involves creation of the computation workflow using the WP3 Impact Monitor framework. All the tools will be integrated using MDAx and RCE and the communication between the tools will be performed through CPACS as standard. The computation workflow will then be executed in step 4 as part of the design studies, such as optimisation, design of experiments, sensitivity analysis, etc. Finally, in step 5, the results of the design studies will be analysed and compared through maps and charts using the WP4 Dashboard Application. In addition, the capabilities to modify the computational workflow and performing what-if trade-off design studies will be demonstrated in step 6.

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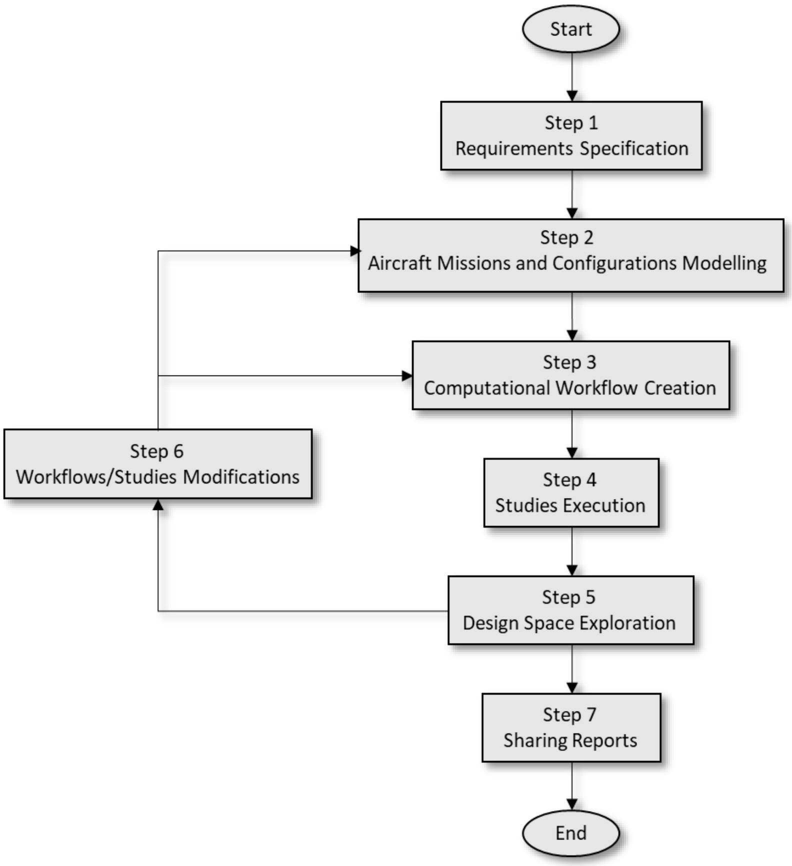

Figure 3-2: Use case storyboard

Currently utilizing all the aforementioned tools, the tentative workflow designed in MDAx tool for UC 1 is shown in Figure 3-3. Some modifications can be noted, compared to the previous deliverable. First of all, all the models' connection are now corresponding the CPACS inputs and outputs data. In addition, a convergence loop will now ensure a consistent engine aircraft sizing aspect of the study. Once the engine and aircraft convergence loop is complete, the aircraft details will be passed to another tool being developed under the name 'CPACS2BADA Converter', which will translate the details into the BADA files that can be directly consumed by the next tools in line for trajectory modification and emission/contrail modelling.

Table 2: UC1 tool integration status

Tool	CPACS connection		RCE integration	
	Read & write XML	Data integrated into CPACS	Tool integrated locally	Connection to Uplink server established
Turbomatch	☑	☑	☑	☑
SAUVE	☑	☑	☑	☑
AECCI	☑	☑	☑	☑

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DYNAMO	☑	☑	☑	☑

Table 2 shows that for UC1 all tools were connected to CPACS and integrated into RCE. As the HAT tool is not integrated directly in RCE, but as a service in the dashboard, it is not listed in the tool integration status. Table 2 also shows that for UC1 all tools were connected to CPACS and integrated into RCE. As the HAT tool is not integrated directly in RCE, but as a service in the dashboard, it is not listed in the tool integration status.

Figure 3-3 shows that the workflow starts with SUAVE, which takes external inputs as reference aircraft model top-level requirements/details and other specific inputs such as thrust, fuel mass flow, mission definition and calibration factors etc. With these initial parameters, SUAVE models and calculates the thrust requirements and passes them to TurboMatch (engine modelling) with data such as altitude, Mach number, thrust, power and atmospheric models. Turbomatch then simulates the engine and creates an engine deck for the required thrust settings at various altitudes and Mach numbers with some other parameters. This output from Turbomatch is fed back into SUAVE and the process is repeated in a loop so that engine and aircraft optimization is performed and a solution is converged and obtained.

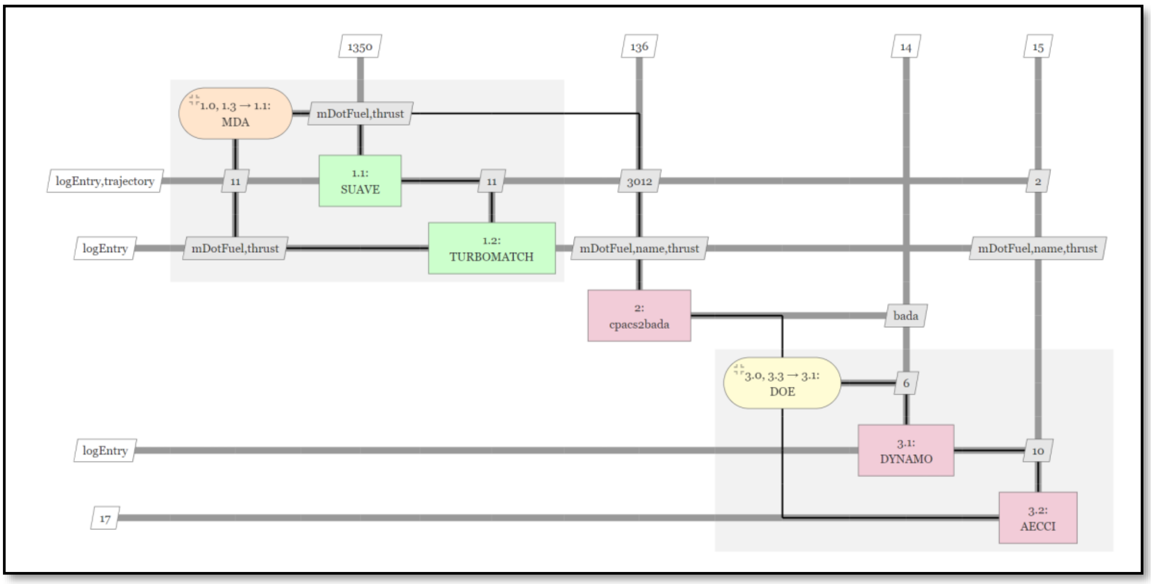

Figure 3-3: MDAx workflow for UC1

Once an aircraft engine model is obtained from the first convergence loop, the details are converted into Bada files by CPACS2BADA converter and then further passed to a Design of Experiment (DoE) loop of DYNAMO and AECCI tools for trajectory and emissions modelling and analysis. Parameters such as trajectory points, time, distance, thrust, altitude, etc. are exchanged between DYNAMO and AECCI, and AECCI provides various emission-related information for CO, CO2, NOx, SOx, HC, soot and contrails. For the provided aircraft models, different combinations of payloads, trajectories, atmospheric conditions, etc. are used to perform design of experiments obtaining different sets of

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results. Finally, the analysis results are obtained at the end of this workflow for different studies such as aircraft performance, engine performance, trajectory performance and emissions performance.

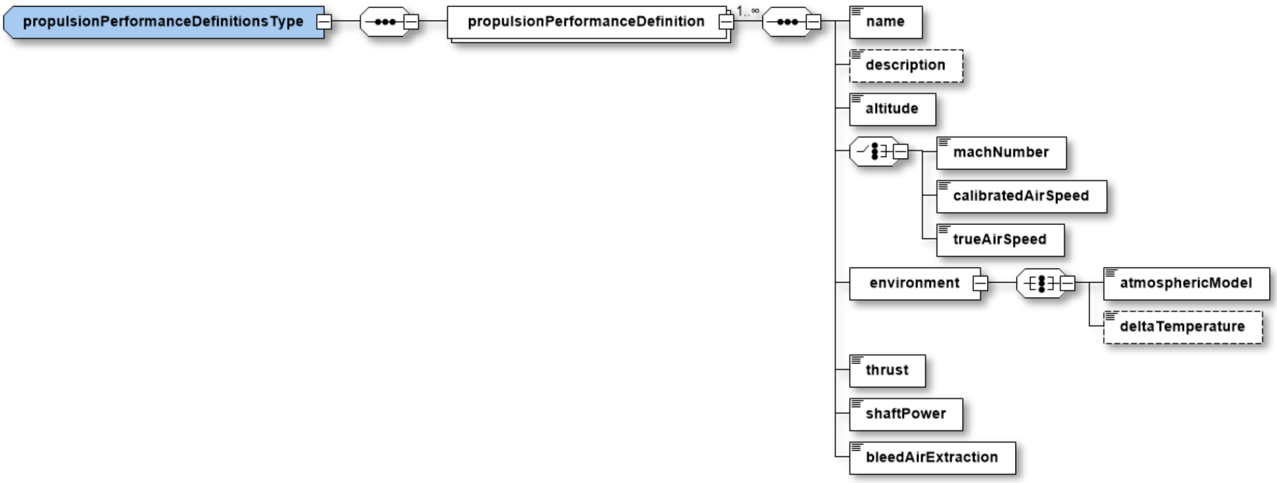

Figure 3-4: CPACS structure to define propulsion performance requirements

The CPACS data model was modified for the workflow described above. Firstly, it was extended to include <propulsionPerformanceDefinitions>. The associated data type, which defines the hierarchical arrangement of its child elements, is shown on Figure 3-4. This allows to define the requirements for <thrust>, <shaftPower> and <bleedAirExtraction> for various sets of <altitude> and <speed> (<machNumber>, <calibratedAirSpeed> or <trueAirSpeed>).

A further adaptation of the CPACS data model concerns the trajectories. These are a list of elements, each of which has a semicolon-separated vector as data type. For Impact Monitor, not only was the camelCase syntax corrected compared to the official base schema, but additional emissions (<soxFlow> and <h2oFlow>), lift coefficients (<cl>, <cd>), contrail conditions, and others were also included (see Figure 3-4).

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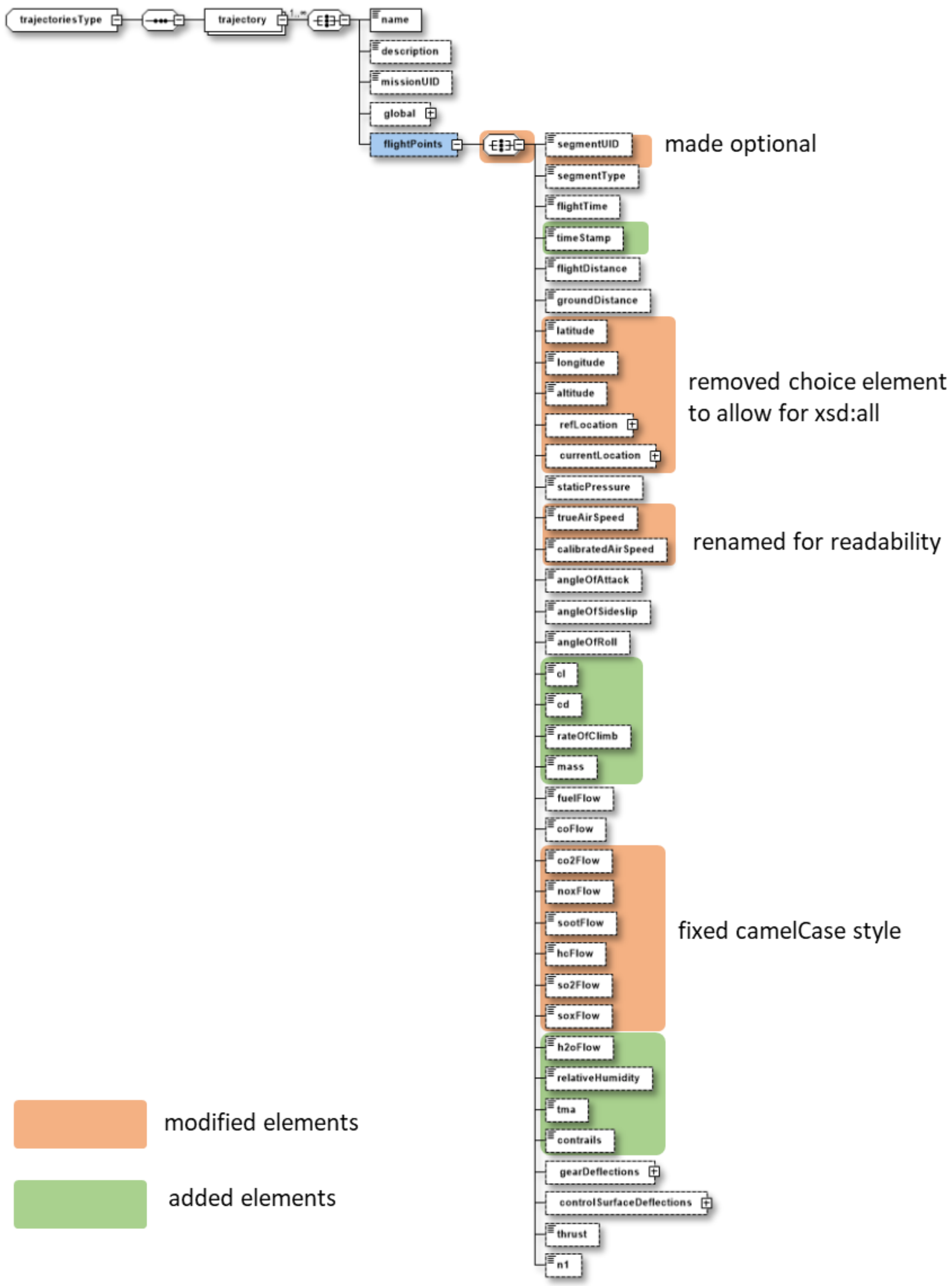

Figure 3-5: Extended CPACS trajectories

3.3 Preliminary Demonstration

Proof of concept for TURBOMATCH (CU) & SUAVE (USTUTT)

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To demonstrate the remote workflow execution capability of the framework, an initial proof-of-concept was planned for UC 1, where two tools, TurboMatch from Cranfield University and SUAVE from the University of Stuttgart, collaborated and were connected remotely (see Figure 3-6). These models were selected as they are at the start of the workflow sizing the aircraft concept. In addition, they require a converger loop. Using RCE and RCE Uplink (see Sec. 2.3), a remote connection between two tools was successfully established. During the proof-of-concept demonstration, one iteration of engine and aircraft sizing was performed.

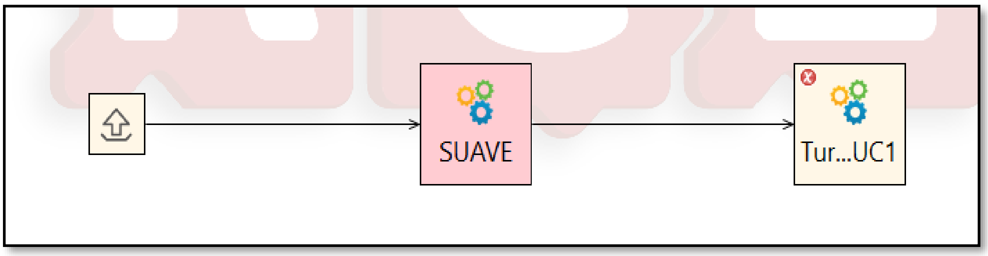

Figure 3-6: Initial Proof of Concept demonstration using just two tools

At a later stage, a converger was introduced to perform multiple iterations of engine and aircraft sizing, which is a work in progress.

The following section presents the steps to set up the workflow and perform remote execution in RCE via Uplink. The steps include initial setup and testing of the convergence loop for aircraft engine sizing via RCE Uplink.

STEPS INVOLVED:

1. Update the *Input Provider* block to add a new input file that will be used only once (for the first run of iterations). Select a name and path for the initial input file to initialize the first run, shown as “CPACS_in” in the figure below. In the Turbomatch tool integration, add another input for the passed file (set this file as “Queue (consumed)”, the initial input should be set as "Single (consumed)". This other file “CPACSForward” will be used in the following iterations.

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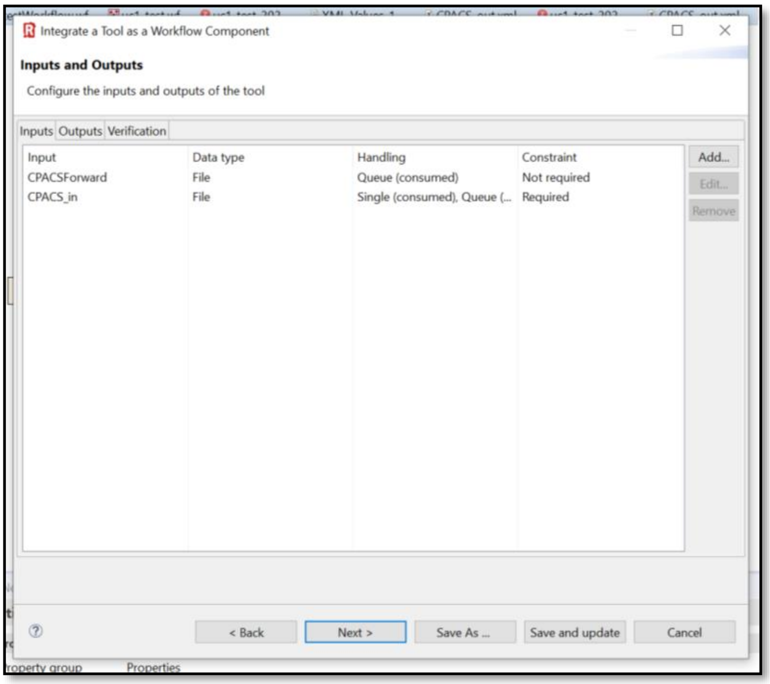

Figure 3-7: Using two input files for the first and rest of the iterations.

2. Insert the tools to setup the basic workflow. In this case we are using 'Turbomatch' and 'SUAVE', drag them to workflow window and then proceed to setup the connections between the tools and input provider.
3. Now, insert an *XML Values* block (from the right panel - XML-XML Values) for the value to be checked before starting the convergence or running iterations.
4. Add Output at the XML Values Block (float); which is 'MTOM' in our case and choose the xPath accordingly as shown in Figure 3-8.

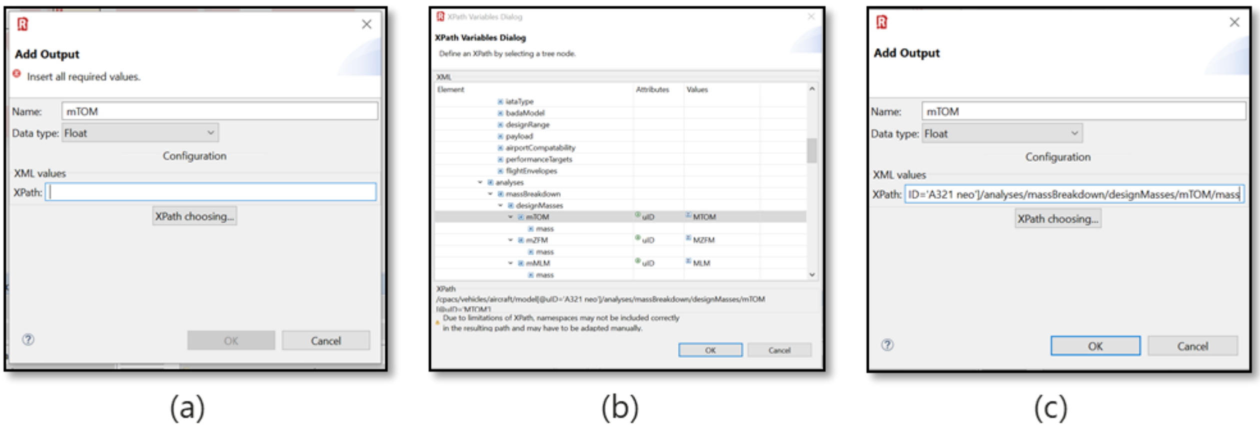

Figure 3-8: Adding the XML value to be checked and selection of its XPath from CPACS

5. Drag and drop the *Converger* block to setup the convergence loop for further iterations.
6. Set up the *Converger* and fill out the required details. (Evaluation – Converger) – Choose Convergence Criteria, Choose Value (float – mTOM) to converge and then choose XML, which is forwarded, set as "Nested Loop" (see Figure 3-9).

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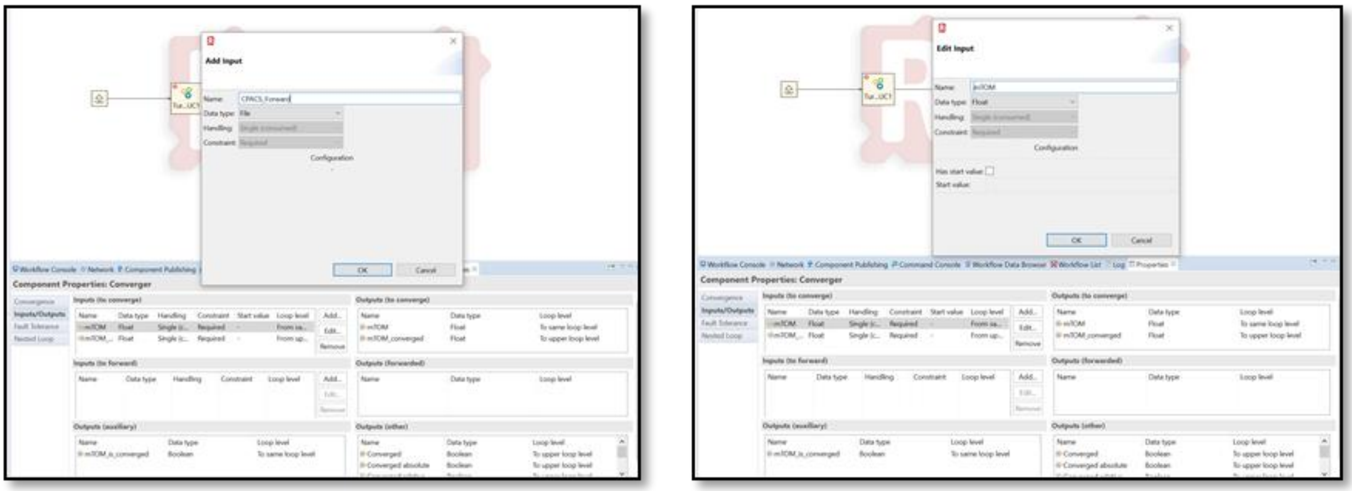
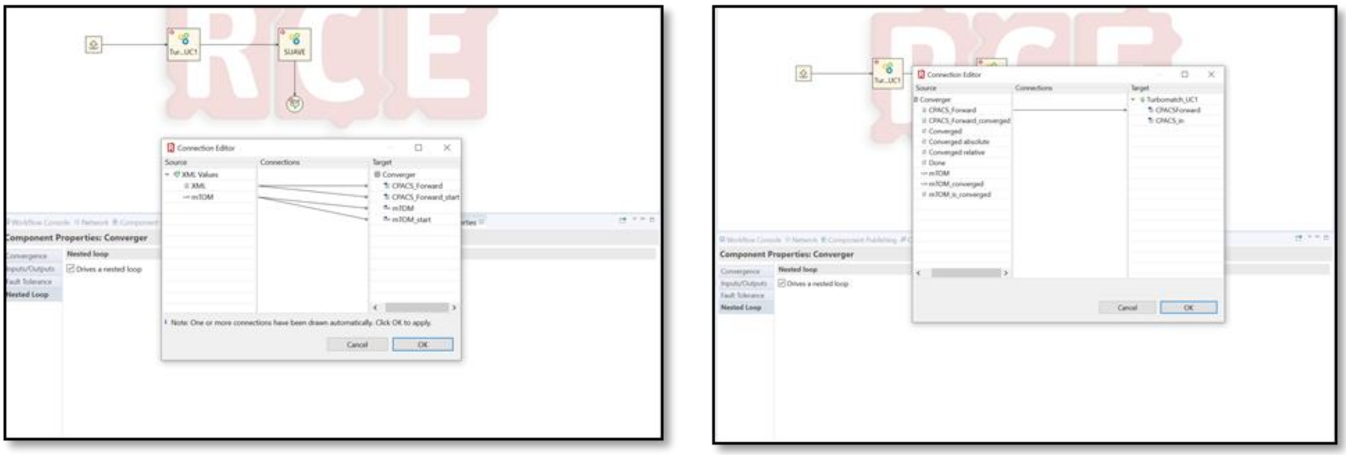


(a) (b)

Figure 3-9: Setting up the *Converger* block

7. As all the blocks have been setup, the components are connected andthe workflow is complete (see Figure 3-10).



(a) (b)

Figure 3-10: Specifying the data connections

At this stage, the basic setup of two tools with the convergence loop has been implemented, which could be executed remotely from anywhere and the tools may be executed on the host machine or server without sharing the intellectual property/tool access. If required, one of the tools can be taken offline by simply disconnecting the uplink server. Once disconnected, no other person can use that tool in any workflow for execution.

Figure 3-11: Initial workflow involving Turbomatch and SUAVE with convergence loop

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This preliminary demonstration has been achieved thanks to the encapsulation of the models in CPACS, their individual integration in RCE, and the ability of this framework to remotely connect any tool, creating a workflow with a number of tools, allowing remote access through the Uplink feature. Furthermore, in the next step, all the tools of Use Case 2 will be remotely connected through RCE to set up the complete workflow that can be executed globally without sharing the tools.

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4. Use Case 2: Continuous Descent Operations

In Work Package 5, UPC is leading the task on "Technologies, Operational or process improvements on Airport Level", while also contributing to the Use Case on "Continuous descent Operations" through modelling and simulation of an impact-assessment at aircraft and airport level. Details of the Use Case can be found in upcoming sections.

Figure 4-1: Aircraft Level Assessments (Use Case 2)

4.1 Scenario Definition

Use Case 2 (UC2) focuses on the implementation of Continuous Descent Operations (CDO) on airport approach trajectories. The assessment of the level of implementation and the impact on emissions, noise, risk, and capacity of the airport and the airport environment is the main objective of the use case. The definition and objectives provided in the D5.2 Use Case Definition document remain the same.

The use case is based on the analysis of the arrival trajectories to a given airport. Increasing the demand level while keeping an affordable level of CDO approaches will enable to assess not only the effects of CDO on the capacity of the airport, but also to assess the impact in terms of fuel consumption reduction, so emissions reduction, as well as noise footprint reduction. The risk associated to the operations in the vicinity of the airport is also part of the assessment.

Clearly, a baseline is required to perform the assessment. In this case, a scenario without CDO and a large demand will be defined. This scenario does not need to consider maximum throughput capacity of the given airport, but a capacity close to the practical capacity, when an acceptable level of delay could be detected. Following ICAO recommendations, a delay below 4 minutes, in average, is the level to be considered.

Regarding the scenarios with CDO, a set of them will be proposed to assess different levels of CDO implementation. From a low demand scenario, which should allow a larger number of CDO approaches, to a larger demand scenario, which could limit the use of the CDO strategies.

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In any case, it has been decided to use a generic airport, named *CAEPport*, to define the airport configuration. The traffic scenario will be defined to fit a real airport, while using it as the baseline to define the required demand levels. Realistic weather conditions will be reproduced thanks to the use of the weather data for the simulations of the traffic around the airport and the trajectory simulations.

As described in the D5.2 document, the tools involved in the test case are listed in Table 3.

Table 3: UC2 tools overview

Tool name	Description	Tool vendor
Scheduler	Provides a flight schedule associated to aircraft type, Origin-Destination pair, leg distance, arrival time and departure time.	DLR
AirTop	Based on the flight schedule (and airport and airspace data and aircraft-performance characteristics) realistically simulates the aircraft movements at and around the airport.	NLR
DYNAMO	Computes refined 4-D trajectories including CO2, fuel flow, thrust, etc. along the whole trajectory or limited to a specific stage.	UPC
Tuna	The noise model processes the 4-D trajectories from AirTop to generate Lden/Lnight and (when combined with a population density database) population impacted (and highly annoyed and highly sleep disturbed).	NLR
LEAS-iT	The emissions model processes the 4-D trajectories from AirTop to generate total emissions (e.g. CO2, NOX) below 3,000 ft.	NLR
AECCI	Using 4-D trajectories from DYNAMO, generates accurate emissions prediction.	ONERA
TRIPAC	The third-party risk model processes the 4-D trajectories from AirTop to generate individual and societal risk.	NLR
SCBA	Conducts the overall societal impact assessment.	TML

4.2 Technical Implementation

The Use Case 2 implementation is based on the set of tools listed in the previous section. These tools are arranged on the workflow shown in Figure 4-2. It has been updated and adjusted along the project discussions, and the one shown here is the latest version.

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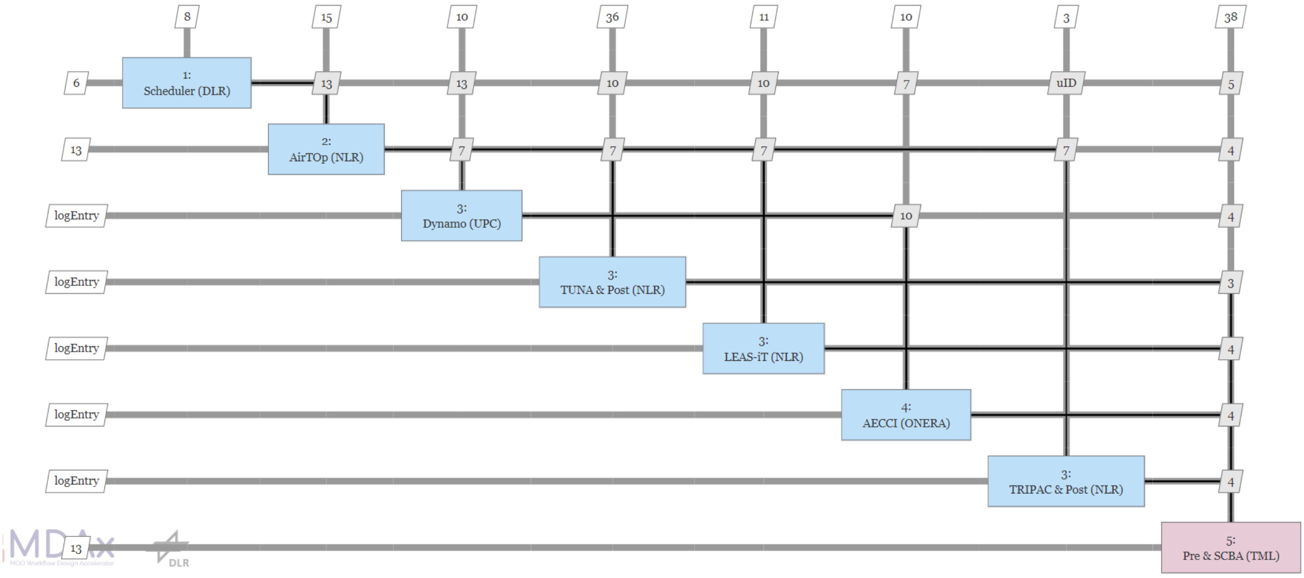

Figure 4-2: UC2 workflow

With respect to the UC2 workflow, the CPACS schema must meet the following requirements:

- SCHEDULER needs to provide a **flight schedule** with OD (Origin-Destination) pair, and arrival and departure time.
- Extended information about the **airport** (CAEPport) needs be included, to be used by AirTop and DYNAMO.
- Aircraft information for new configurations will be included providing the path to the OPF file, which will reproduce the BADA data, and some parameters will be also inserted directly at CPACS. Aircraft information for standard and existing configurations will be defined through the **BADA, ICAO and IATA type designators**. A nomenclator list has been already shared among the partners to verify the definition of the aircraft models.
- **Trajectories**: two sets of trajectories will be available. The first one will be linked to AirTop output, while the second one with DYNAMO output.
- DYNAMO trajectories; a particular characteristic of the trajectories by DYNAMO is that they will include **weather data**, more precisely the relative humidity, along the trajectory points.

To meet these requirements, the CPACS schema has been extended. At the highest CPACS level, which also already included <airports>, <flights>, and <airlines>, a new <schedules> element has been added to define flight schedules. To be able to combine schedule information with detailed flight and airport data, the <airports> and <flights> elements have been revised (see Figure 4-3).

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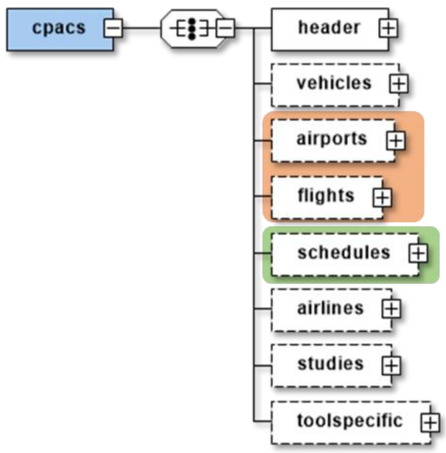

Figure 4-3: Elements modified (orange) and added (green) to CPACS

The <schedules> element is of type schedulesType, which is shown in Figure 4-4. This allows multiple schedules to be defined in CPACS. Each of these schedules consists of a <name>, <description>, <startDate> and <endDate>. In addition, elements from the <flights> node can be linked via a uID attribute. Analyses for a specific schedule can be stored directly in the <schedule> node. Currently, an <emissions> element has been implemented to share climate assessment results.

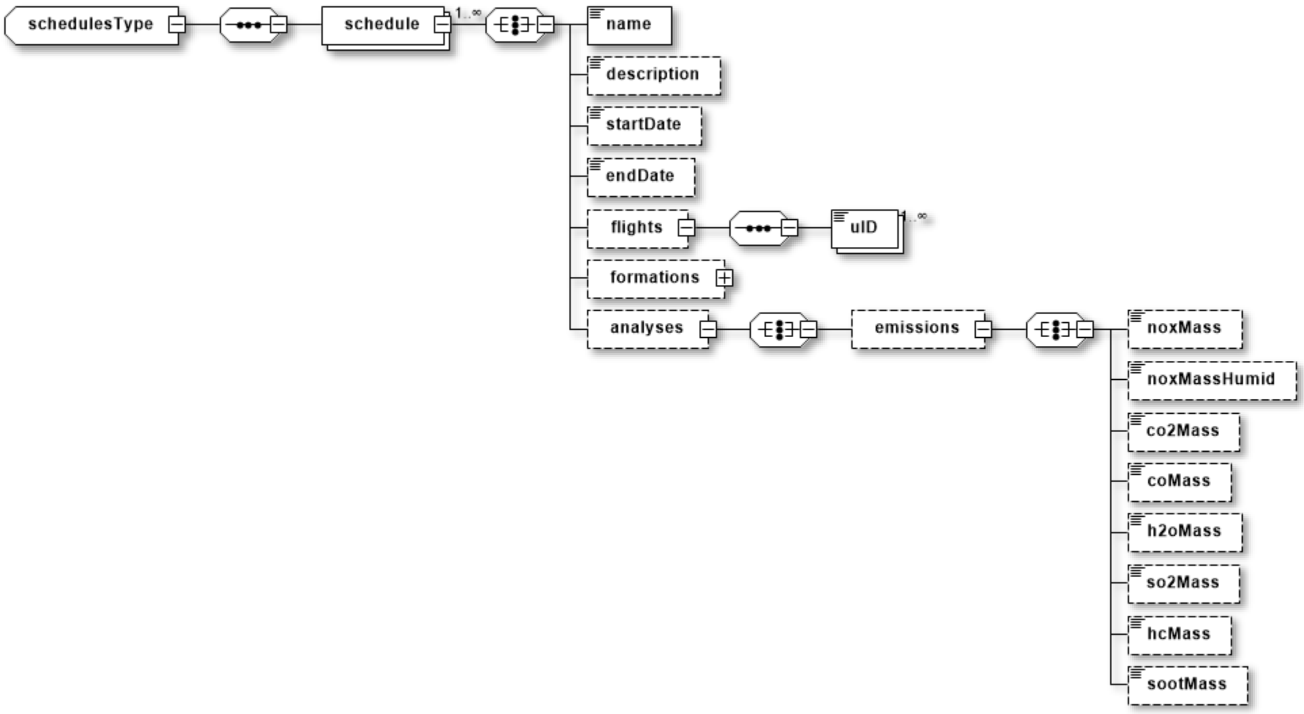

Figure 4-4: CPACS schedulesType as used for the newly introduced <schedules> element

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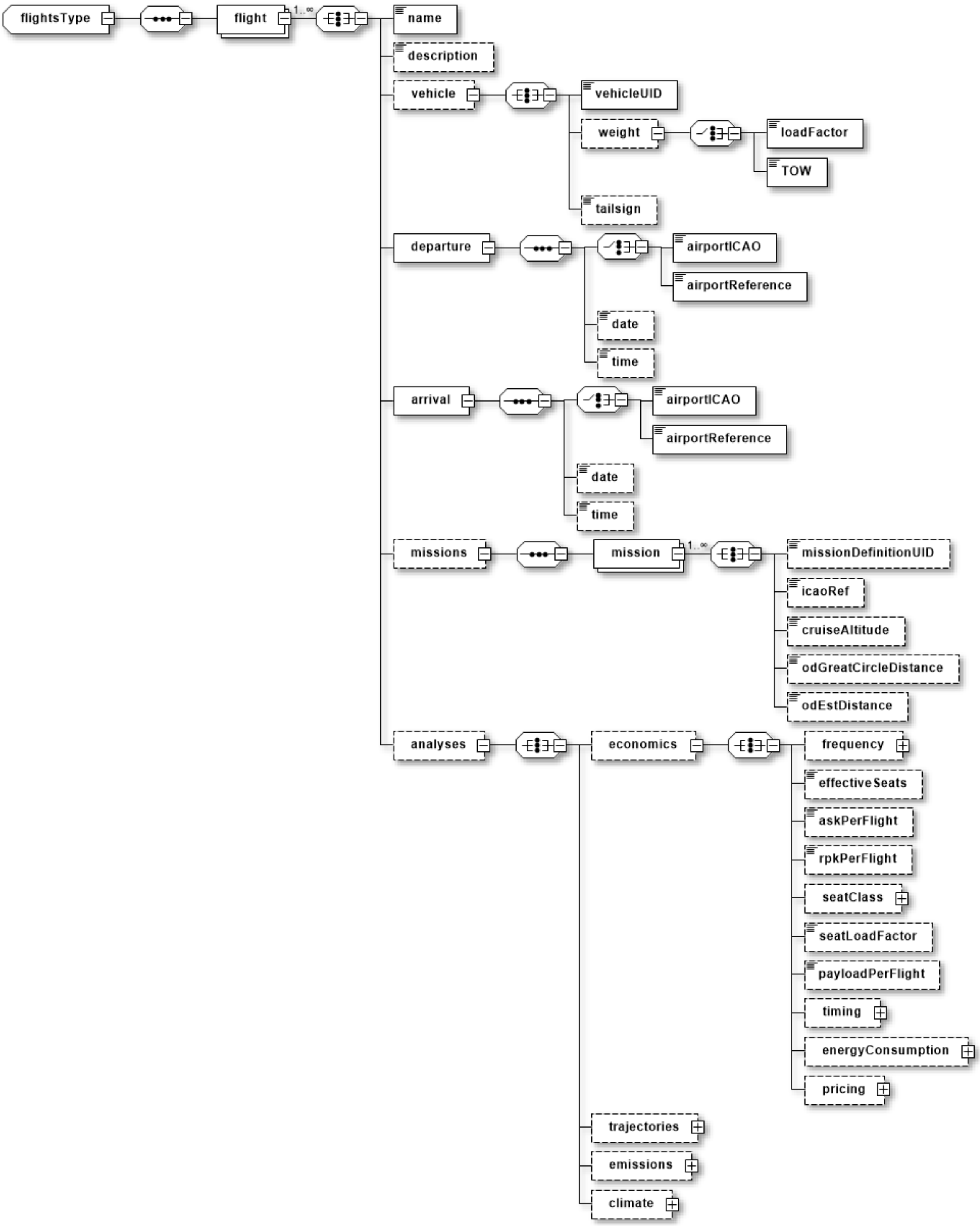

Figure 4-5: CPACS flightsType

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A corresponding <flight> is shown in Figure 4-5. The flightsType is assigned to the <flights> element in Figure 4-3. Such a flight contains a uID reference to the vehicle used, which can be <aircraft>/<model> or <rotorcraft>/<model>. In Impact Monitor, only the former is used. In the simplest case, this element only contains an IATA, ICAO or BADA type designator, which has been added to the corresponding <global> node (see Figure 4-6). Next, the OD pair is mapped via <departure> and <arrival>. Both have the same structure, which allows either a reference to an airport defined in CPACS or an ICAO reference. The date and original time are also specified. The <missions> node allows the reference of flight plans, which are defined via a uID link to a corresponding <missionDefinition>. The great circle distance and estimated distance can also be specified. The <analyses> node offers the option of exchanging flight-related analysis results on economic (<economics>) and environmental (<emissions>, <climate>) aspects. The <trajectories> node is of type trajectoriesType, which is why the sub-nodes shown in Figure 3-5 are available here.

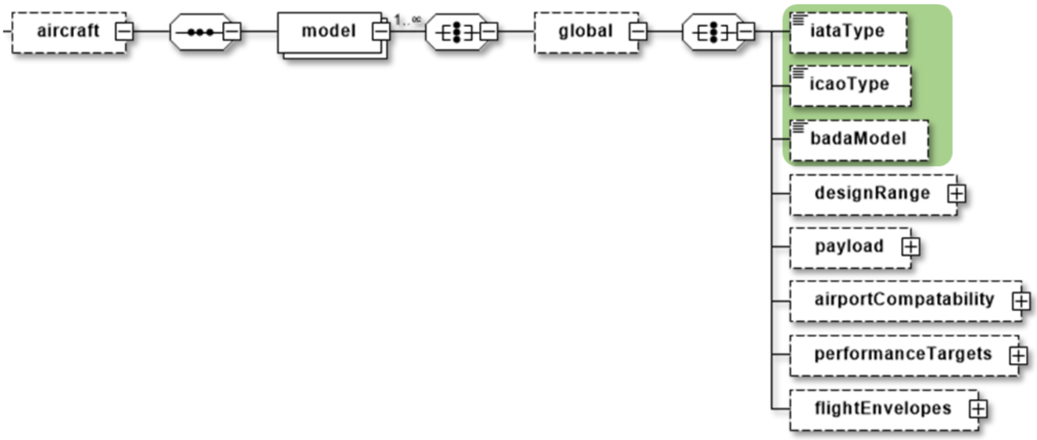

Figure 4-6: Added aircraft type information

To execute the workflow remotely, an RCE UPLINK connection was established as described in Sec. 2.3. Figure 4-7 shows the special case of DYNAMO integration in RCE. However, other tools may also be available, as shown in the Figure with SUAVE from the University of Stuttgart. The tool integration status for UC2 is summarized in Table 4. The connection via BRICS will be part of the next steps.

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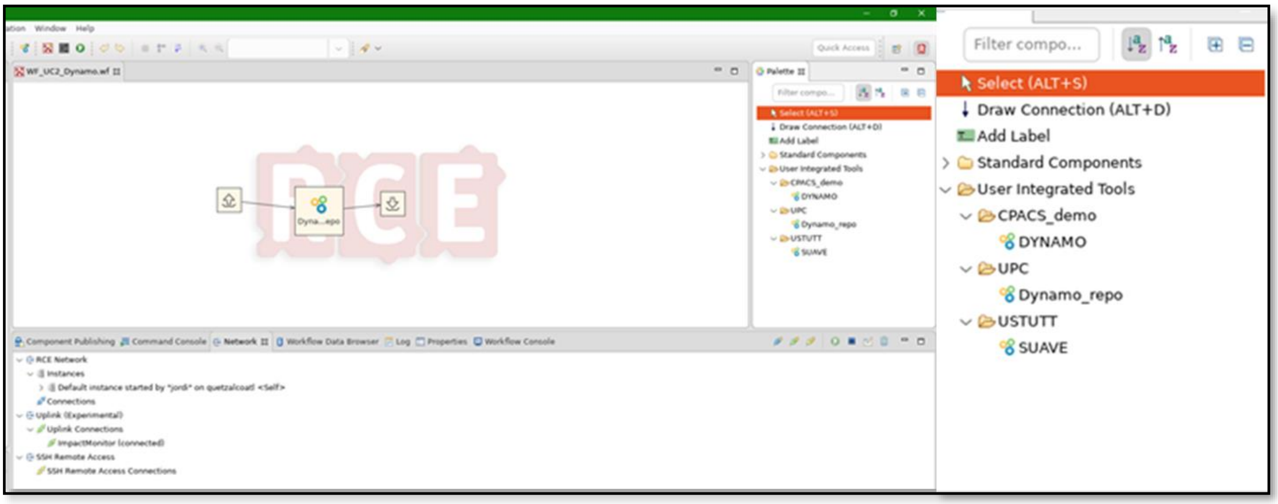

Figure 4-7: RCE with active DYNAMO connection

Table 4: UC2 tool integration status

Tool	CPACS connection		RCE integration		
	Read & write XML	Data integrated into CPACS	Tool integrated locally	Connection to Uplink server established	Connection via BRICS established
Scheduler	☑	☑	☑	☐	-
AirTop	☑	☑	☑	-	☐
DYNAMO	☑	☑	☑	☑	-
Tuna	☑	☑	☑	-	☐
LEAS-iT	☑	☑	☑	-	☐
AECCI	☑	☑	☑	☑	-
TRIPAC	☑	☑	☑	-	☐

Once the integration is complete, the steps towards a full simulation of the workflow are expected to be:

1. Integration of SCHEDULER (DLR) and AIRTOP (NLR): initial tests are ongoing with a flight schedule definition initiated by DLR.
2. Integration of AIRTOP (NLR) and DYNAMO (UPC): on hold, waiting for the previous integration.

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3. Integration of DYNAMO (UPC) and AECCI (ONERA): work in progress which requires some modifications of DYNAMO. Preliminary tests are in progress without the mentioned modifications, which include the weather data on the CPACS file. This step is common with UC1, where the integration of DYNAMO and AECCI is also required.

4.3 Preliminary Demonstration

For the preliminary demonstration of the of the UC2 workflow, two are the main integration steps that have been considered. The first one affects the tools SCHEDULER by DLR, AIRTOP by NLR and DYNAMO by UPC, while the second one affects DYNAMO and AECCI by ONERA.

With these two steps in mind, the first one, regarding mainly Scheduler and AirTop has been considered as the most appropriate, due to the fact it is the first step on the workflow, but also because it shows a higher level of maturation.

To deliver this integration, the MDAx workflow has been used as the seminal definition. As described earlier, this MDAx workflow has been used for defining the interaction among the tools. For the particular case of Scheduler and AirTOp, Figure 4-8 highlights the connection points between the two tools as it can be shown in the MDAx application. This information is automatically derived from the CPACS integration of both tools, that has been made possible either by re-using existing labels or creating new ones (as explained in 4.2)

Figure 4-8. Scheduler – AirTop coupling variables in MDAx

Basically, Scheduler aims at producing flight schedule. It does not require any specific input from other tools from the workflow, even though it requires the definition of several own inputs like the fleet, the time range, among others, all defined in the agreed scenario. The flight schedule sorts the flights along the timeframe and associate the aircraft type to the flight.

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Thanks to these information, AirTOp will then simulate the arrivals and define the specific time and queue to operate around the selected airport of the study. The delay this queue could originate can also be calculated, here as an output from AirTOp. For instance, Figure 4-9 provides an overview of the data transferred from AirTop to DYNAMO including this delay information.

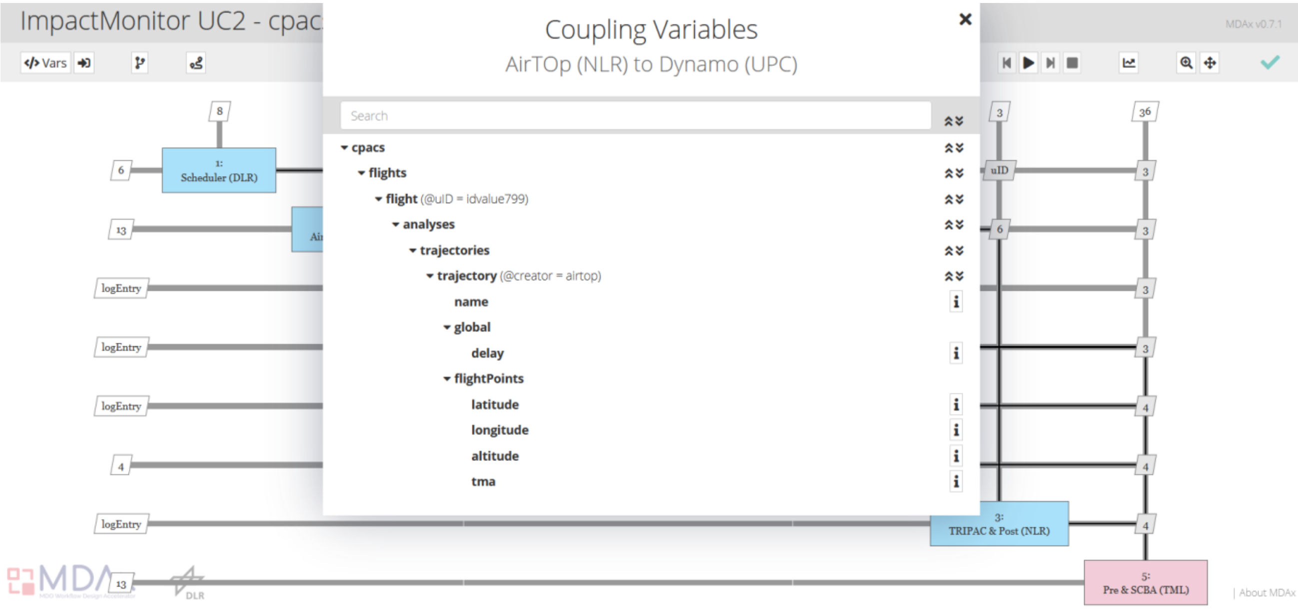

Figure 4-9. AirTop – DYNAMO coupling variables in MDAx

Therefore, the combination of Scehduler and AirTop brings the expected result associating the schedule and the trajectories each flight performs on arrival. Figure 4-10 and Figure 4-11 show the obtained output, with the flight schedule and the flight trajectory. A visualization of the departure and arrival tracks for the scenario on CAEPort is provided on Figure 4-12.

Each flight has its own trajectory, which will fulfil the condition of performing a continuous descent as far as possible. This condition will be set up later, and will provide more or less freedom of action according to the simulated scenario.

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```xml
<?xml version="1.0" encoding="utf-8" standalone="no"?><cpacs xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation=
"https://www.cpacs.de/schema/v3_4_impactMonitor/cpacs_schema.xsd">
  <header>
    <name>Schedule</name>
    <version>1.0.0</version>
    <versionInfos>
      <versionInfo version="1.0.0">
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        <timestamp>2024-05-15T12:08:04</timestamp>
        <description>This is a schedule data set</description>
        <cpacsVersion>3.4</cpacsVersion>
        <changeLog>
          <logEntry>
            <creator>Sreyoshi Chatterjee</creator>
            <timestamp>2024-05-15T12:08:04</timestamp>
            <description>create initial schedule</description>
          </logEntry>
        <logEntry><creator>Peter Hoogers</creator><timestamp>2024-05-29 02:30:23</timestamp><description>performed AirTOp run</description></logEntry></changeLog>
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    </versionInfos>
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        <global>
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        </global>
      </model>
      <model uID="model_A35N">
        <name>Airbus A35N</name>
        <global>
          <icaoType>A35N</icaoType>
        </global>
      </model>
      <model uID="model_BCS3">
        <name>Airbus BCS3</name>
        <global>
          <icaoType>BCS3</icaoType>
        </global>
      </model>
```


Figure 4-10. Flight Schedule as processed by AirTOp


```xml
    944;65.8368;61.8744;58.216800000000006;54.254400000000004;50.5968;46.6344;42.976800000000004;39.0144;35.3568;31.3944;27.736800000000002;23.7744;20.1168;14.9352;9.7536;4.8768;
    0.3048</altitude></flightPoints><global><delay>0.0</delay></global></trajectory></trajectories></analyses>
  </flight>
  <flight uID="flightY205059">
    <name>EGBB-KJFK</name>
    <vehicle>
      <vehicleUID>model_A20N</vehicleUID>
    </vehicle>
    <departure>
      <airportICAO>EGBB</airportICAO>
      <date>2050-09-14</date>
      <time>09:05:00</time>
    </departure>
    <arrival>
      <airportICAO>KJFK</airportICAO>
      <date>2050-09-14</date>
      <time>11:55:00</time>
    </arrival>
    <analyses>
      <economics>
        <seatClass>
          <classType>8</classType>
          <seatNumber>163</seatNumber>
        </seatClass>
        <seatLoadFactor>0.95</seatLoadFactor>
      </economics>
    <trajectories><trajectory><flightPoints><latitude>
    5.803913055555555;5.805695277777778;5.807466111111111;5.809218333333333;5.810946388888889;5.812642222222222;5.814299444444444;5.815911944444444;5.817473055555555;5.8189763888
    88888;5.820416944444444;5.821788055555555;5.823084444444445;5.824301666666666;5.825434444444444;5.826478888888885;5.827430277777777;5.828285555555555;5.829040833333333;5.
    829791944444445;5.830543888888888;5.831299166666667;5.832059166666666;5.832824444444444;5.833595;5.834370555555555;5.835151111111111;5.835935833333333;5.836724999999995;5.83
    7517777777777;5.838314444444444;5.839114166666667;5.839916944444444;5.840723055555555;5.841531111111111;5.842341666666666;5.843154166666666;5.843968333333333;5.844783888888888
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    77777777;5.853831388888889;5.854657777777778;5.855484722222222;5.856312222222222;5.857139722222222;5.857966944444444;5.858792777777775;5.859618055555555;5.860442777777777;5.
    861266388888889;5.862089166666666;5.862911111111111;5.863731944444444;5.864551944444444;5.865371111111111;5.866189166666667;5.867006111111111;5.867822500000001;5.868638055555
    556;5.869452222222223;5.870265555555556;5.871077777777778;5.871889444444445;5.872699722222222;5.873510277777778;5.874320277777785;5.875130277777778;5.875940000000001;5.87674
    9722222223;5.877559166666667;5.878368611111112;5.879177777777785;5.879986388888889;5.880795277777786;5.881603888888889;5.882412222222222;5.883220555555556;5.884028611111111;5
    .884836111111105;5.885643611111111;5.886451111111111;5.887258333333333;5.888065555555555;5.888872222222222;5.889679166666666;5.890485555555555;5.891291388888888;5.8920974999
    99999;5.892903333333333;5.893708611111111;5.894513888888889;5.895318888888888;5.896123611111111;5.896928333333332;5.897732499999999;5.898536666666666;5.899340555555555;5.900144
    7222222225;5.900948333333334;5.901751666666667;5.902555;5.903358055555556;5.904160833333334;5.904963333333334;5.905765555555556;5.906568055555556;5.90737;5.908171388888889;5.
    908973055555556;5.909774166666667;5.910575000000001;5.911375833333335;5.912176111111111;5.912976666666667;5.913776666666667;5.914576388888889;5.915376111111112;5.91617555555
    5556;5.916974722222222;5.917773888888889;5.918572500000001;5.919371111111111;5.920169444444444;5.920967222222223;5.921765000000001;5.922562777777778;5.923360277777778;5.92415
    7222222222;5.924954166666667;5.925750833333334;5.926547222222222;5.927343611111115;5.928139722222222;5.928935555555556;5.929731111111112;5.930526388888895;5.93132138888889;
    5.932111111111111;5.932894722222223;5.933673055555555;5.934445555555555;5.935212500000004;5.935974166666667;5.936735277777778;5.937490833333333;5.938240833333333;5.9389852
    77777778;5.939724166666667;5.9404575;5.941190555555556;5.941923333333334;5.942656111111111;5.943388611111112;5.944120833333334;5.944852777777778;5.945584444444445;5.94631611
    1111111;5.9470475;5.947778611111115;5.948509444444444;5.949240277777778;5.949970833333333;5.950695833333335;5.951415;5.952128611111111;5.952838333333333;5.953547777777778;5
    .954256944444444;5.954965833333335;5.955674722222223;5.956383333333333;5.957091944444445;5.957800277777778;5.958508333333335;5.959216388888889;5.959923888888895;5.96063111
    1111112;5.961338333333334;5.962045555555556;5.962752222222222;5.963459166666665;5.964165833333333;5.964904166666667;5.965659722222222;5.966425;5.967195;5.967968055555556;5.9
    68742222222223;5.969516944444445;5.970291944444445;5.971066388888889;5.971840833333333;5.972615;5.973389166666667;5.9741625;5.974935833333333;5.975708888888889;5.976481666666
```


Figure 4-11. Flight trajectory associated to each flight on schedule as output by AirTOp

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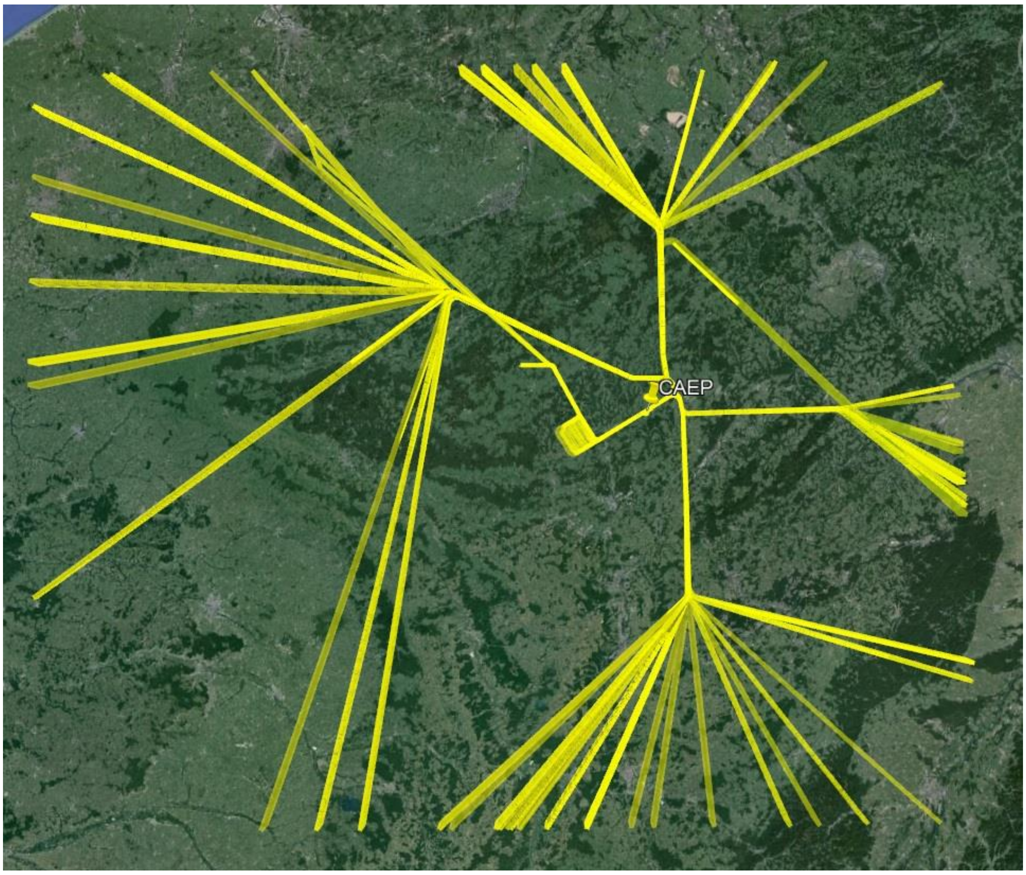

Figure 4-12. Departure and arrival tracks visualization (AirTOp)

This preliminary demonstration has been achieved thanks to the encapsulation of both models in CPACS as well as their individual integration in RCE. This initial step now allows the output CPACS to be propagated to the other tools in the workflow.

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5. Use Case 3: Sustainable Aviation Fuel

In Work Package 5, TML is leading the task on "Technologies, improvements or policies and their impacts on ATS level", while also contributing to the Use Case on "Sustainable Aviation Fuel" through modelling and simulation of an impact assessment at air-transport system level of different policies for the uptake of sustainable aviation fuels.

Figure 5-1: Aircraft Level Assessments (Use Case 3)

5.1 Scenario Definition

In Use Case 3 two policies for the uptake of sustainable aviation fuels (SAF) will be evaluated at air-transport system level (ATS level). In addition to this, there will be a link between the analysis at aircraft level from UC1. The aim of UC3 is thereby to demonstrate the capabilities developed by the Impact Monitor framework and the interactive DA. While the uptake of SAF may also have implications at airport level, this level is not in the scope of UC3. The airport level is covered in UC2.

Compared to the status reported in Deliverable 5.2, the scenario definition has been refined as follows.

Among the scenarios that were considered in Deliverable 5.2, it has been decided that UC3 will compare the impacts of the following two policy scenarios for promoting the uptake of SAF in aviation:

- a blending mandate (as in REFuelEU aviation)
- a carbon tax on aviation fuels.

The policy scenarios will be compared against a reference scenario without specific SAF policies. The reference scenario is based on outlooks for the economic and demographic developments, as well as existing policies (with the exclusion of SAF policies). More particularly, it will be based on an existing scenario that has been developed by DLR.

In addition, it has been decided that the time horizon of UC3 will be 2050 and that the analysis will be done for 2035 and 2050. The geographical scope consists of three broad categories of flights: (1) flights covered by the EU and UK Emission Trading System (EU ETS and UK ETS) (i.e. flights within the

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European Economic Area or EEA + Switzerland + UK), (2) other flights to/from these countries, and (3) other flights.

As determined previously in Deliverable 5.2, the tools listed in Table 5 will be used in UC3.

Table 5: UC3 tool overview

Tool name	Description	Tool vendor
Scheduler	Forecast of air traffic patterns	DLR
Emissions Tool (TCM)	Emissions calculator providing in-flight fuel burn and CO2 emissions based on response surfaces of detailed trajectory calculations	DLR
TRAFUMA	Economic partial equilibrium model for the transport fuel markets	TML
ECOIO	Economic Input-Output model	DLR

5.2 Technical Implementation

This section presents the status of the technical implementation for UC3 "Sustainable Aviation Fuels". The proposed Impact Monitor framework and the design exploration environment (DA) will be employed for the execution of the Use Case. Figure 5.2 gives an overview of the different steps in the implementation plan.

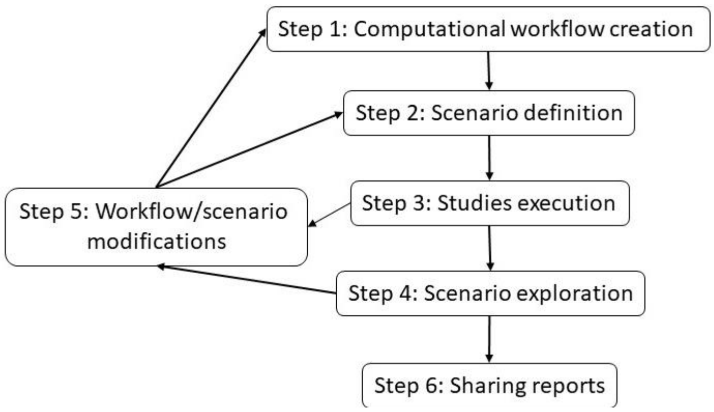

Figure 5-2: Implementation plan Use Case 3

In the first step, the computational workflow for conducting the studies has been set up. As in the other two use cases, the workflow has been developed using the MDAO Workflow Design Accelerator (MDAx). The next figure presents the upgraded general MDAx scheme for the simulation stage in UC3. The figure presents the status on April 3, 2024. The upgrade now includes the integration of the exchange between the tools via CPACS.

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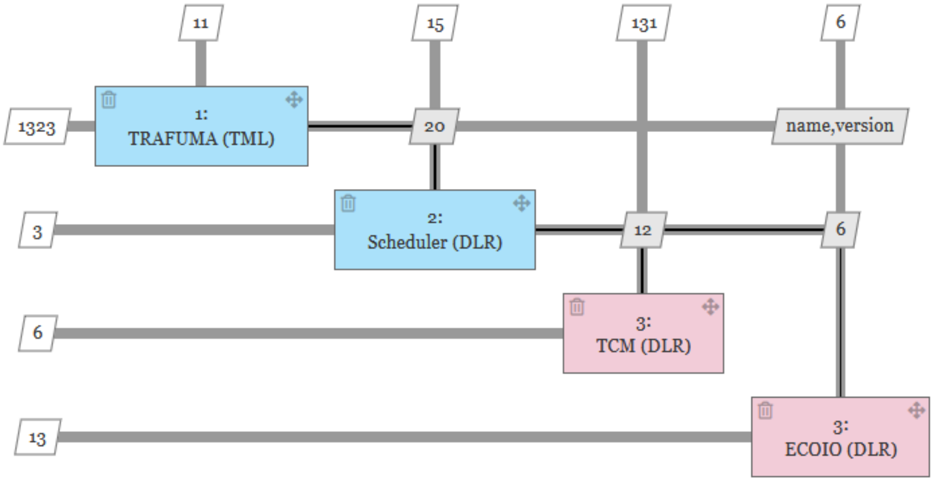

Figure 5-3: XDSM diagram (in MDAx) for Use Case 3 – simulation stage (3 April 2024)

In UC3 there are two stages: the calibration and the simulation stage. The aim of the calibration stage is to construct the reference scenario and to calibrate the TRAFUMA model. First, Scheduler and Emissions Tool will be used to project air travel and aviation fuel consumption and emissions in the reference scenario. This will be repeated for an alternative set of aviation fuel prices. This allows to derive the fuel demand elasticities. Based on this information, the TRAFUMA model will be calibrated in a way that its reference scenario and demand parameters are in line with those of the other two models. By including this calibration stage, the aim was to minimise the need for an iterative loop in the simulation stage.

In the simulation stage the effects of two SAF policy scenarios will be simulated. The effects of these scenarios will be determined compared to the reference scenario that was constructed in the calibration stage. Based on the definition of the policy scenarios, TRAFUMA will first compute the impact of these scenarios on the user price of aviation fuel. The outcome will then be used by Scheduler to compute the impact of the change in the fuel costs on air travel. Next, Emissions Tool will calculate the effects on aviation fuel consumption and CO2 emissions. Finally, ECOIO will compute the broader economic impacts of the SAF policies.

Table 6 shows the current status of the integration of the UC3 tools in CPACS and RCE.

Table 6: UC3 tool integration status

Tool	**CPACS connection**		**RCE integration**	
	Read & write XML	Data integrated into CPACS	Tool integrated locally	Connection to Uplink server established
AirScheduler	☑	☑	☑	☐
Emissions Tool	☑	☑	☑	☐
ECOIO	☑	☑	☑	☑
TRAFUMA	☑	☑	☑	☑

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In order to conduct the UC3 studies, the CPACS data model has been extended by to additional study elements: <airTransportSystem> and <economicImpactAssessment> (see Figure 5-4). A brief summary of these elements is given below.

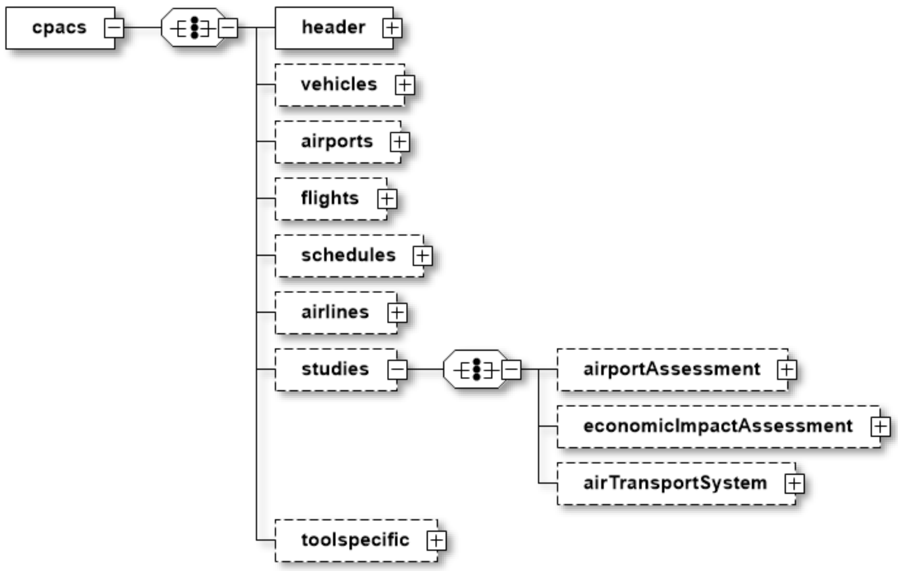

Figure 5-4: CPACS was extended by two study elements: <airTransportSystem> and <economicImpactAssessment>.

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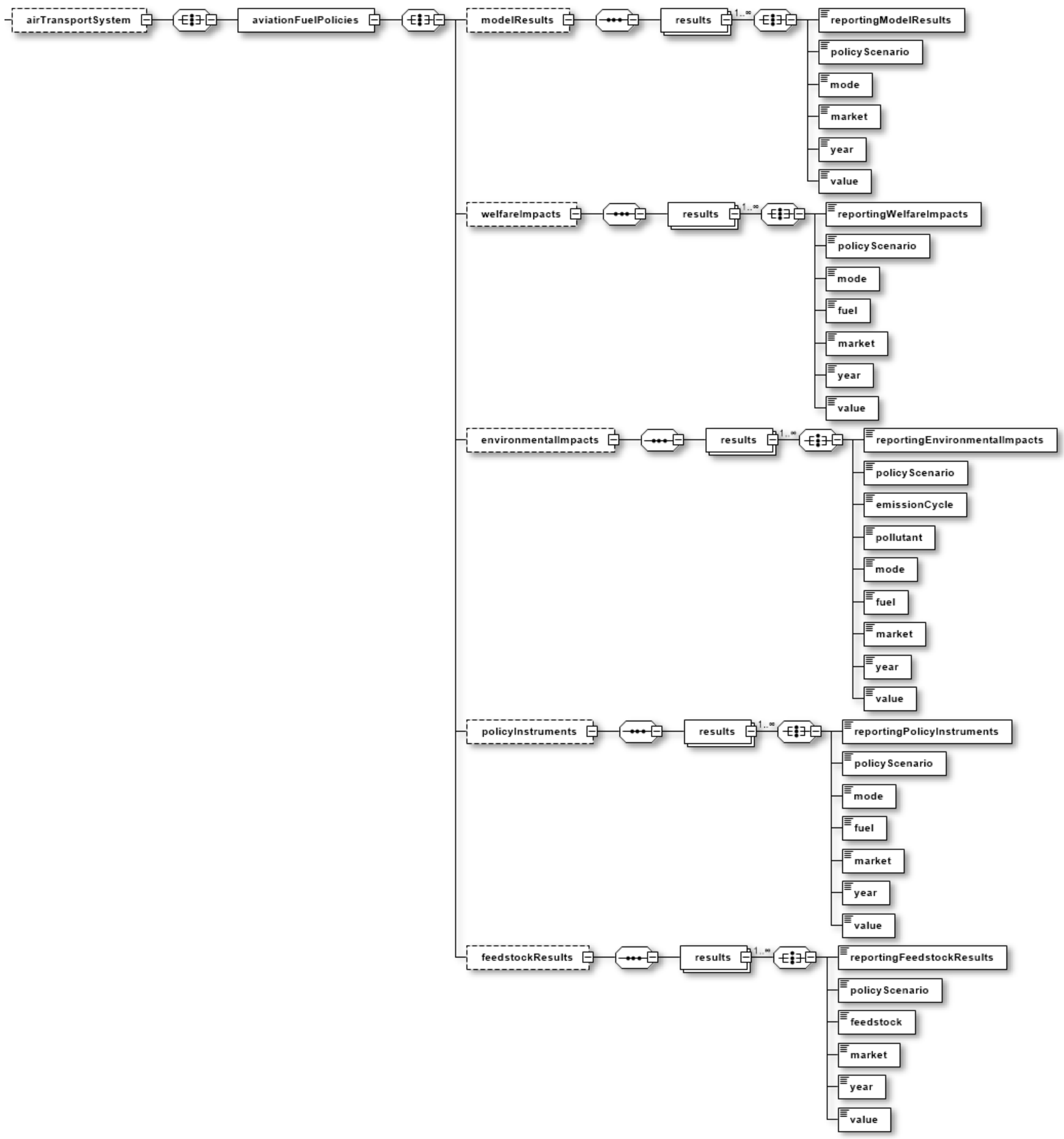

Figure 5-5: Extension of CPACS by the element `<aviationFuelPolicies>`. One can see the sub-elements and their type of occurrence (dashed frame=optional, solid frame=mandatory, stacked=multiple occurrence).

For the TRAFUMA tool, a new <airTransportSystem> element has been created under the <studies> node (see Figure 13). This element currently contains only the <aviationFuelPolicies> node where all the corresponding data is stored. This structure can be extended to include future aviation system study elements as required, providing good scalability for future projects and research activities. The

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<results> sub-node represents the results for the fuel price in the business as usual scenario for all aviation fuels. The different outputs of the TRAFUMA model are stored in sibling nodes, including <modelResults>, <welfareImpacts>, <environmentalImpacts>, <policyInstruments> and <feedstockResults>. They all have a similar structure. Note that each <results> node carries a unique ID attribute (uID). The <results> element combines the information of the <reportingModelResults>, <policyScenario>, <mode> and <fuel> sub-nodes. The results are reported in vector format in the <value> node for the corresponding <market> and <year>. As there may be different markets and different years, the values in these nodes may be repeated. These vectors carry comma separated values, where elements with the same index belong together.

The general settings of the TRAFUMA model are saved under the <toolspecific> node. This stores the labels defining which type of emission scenario (<EMSCEN>), elesticity scenario (<ELASSCEN>), and

```
<studies>
<airTransportSystem>
    <aviationFuelPolicies>
      <modelResults>
        <results uID="rep_P-SCBAU-AIR-ALL">
          <reportingModelResults>P</reportingModelResults>
          <policyScenario>SCBAU</policyScenario>
          <mode>AIR</mode>
          <fuel>ALL</fuel>
          <market>...;...;...</market>
```

cost scenario (<COSTSCEN>) are used in the modelling. This node also lists all the unique IDs of the results stored in the CPACS output.

```
<toolspecific>
  <tool>
    <name>TRAFUMA</name>
    <version>1.0.0</version>
    <trafuma>
      <settings>
        <setting>
          <EMSCEN>CENTRAL</EMSCEN>
          <ELASSCEN>CENTRAL</ELASSCEN>
          <COSTSCEN>COSTMED</COSTSCEN>
```

Code 1: Toolspecific XML for the TRAFUMA model

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CPACS element <economicImpactAssessment>

For the ECOIO tool, a new element <economicImpactAssessment> has been created under the <studies> node to store the model results. This branch contains an <assessmentCase> node for each schedule provided by the Scheduler model. Figure 5-6 shows the structure of this branch along with an example <assessmentCase> node and <economicMap> sub-node. This economic map contains the results for the gross value added (GVA) and employment generated by the aviation industry in 2050 for each country. A distinction is made between direct, indirect, induced and total GVA and employment. The results for each country are stored in vector format (separated by semicolons) under the corresponding sub-nodes. The <industry> element indicates whether the results are related to 'Air transport', 'Air transport related services', 'Aircraft MRO', or 'Aircraft Manufacturing'.

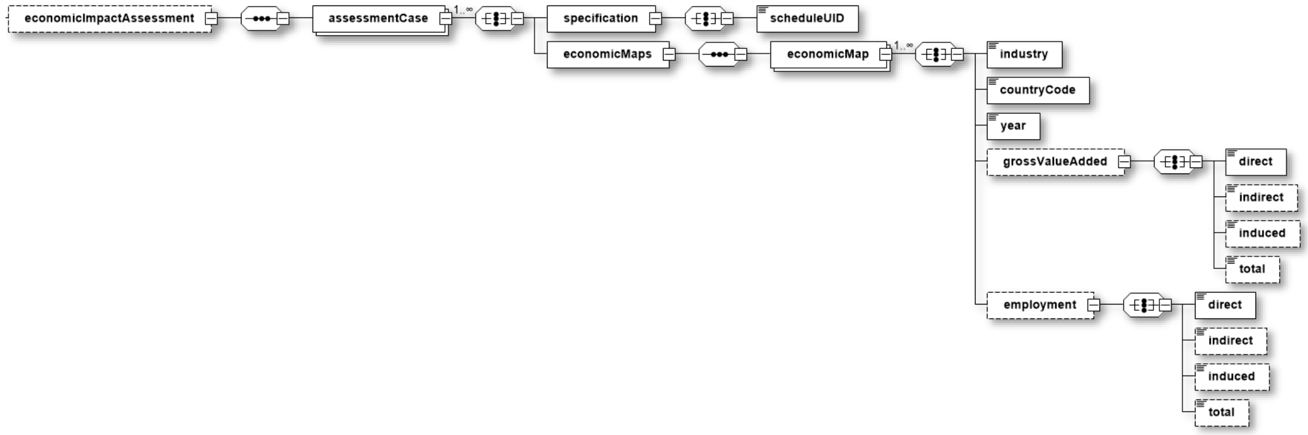

Figure 5-6: Extension of CPACS by the element <economicImpactAssessment>. One can see the sub-elements and their type of occurrence (dashed frame=optional, solid frame=mandatory, stacked=multiple occurrence).

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```
<studies>
  <economicImpactAssessment>
    <assessmentCase>
      <specification>
        <scheduleUID>schedule_2050</scheduleUID>
      </specification>
      <economicMap>
        <industry>Air tranport</industry>
        <countryCode>…;…;…</countryCode>
        <year>…;…;…</year>
        <grossValueAdded>
          <direct>…;…;…</direct>
          <indirect>…;…;…</indirect>
          <induced>…;…;…</induced>
          <total>…;…;…</total>
        </grossValueAdded>
```

Code 2: Example XML code for economic impact assessment

Step 2 in the implementation plan, in which the reference scenario and policy scenarios are defined, has been refined (see Sec. 5.1). In the upcoming months, the workflow will be executed (Step 3). At this stage, where relevant, some models will be optimized in order for them to be integrated smoothly in the workflow. In Step 3, RCE will be used to automatically generate the policy evaluation. In the course of this process, it will be checked whether full automation of the execution is possible, or whether intermediate checks by the modellers will need to be included. Finally, in Step 4 the scenarios will be explored. Selected inputs and outputs of ECOIO, Scheduler, TCM and TRAFUMA will be stored in the CPACS data file. The modellers will be able to visualise these data in the DA.

5.3 Preliminary Demonstration

For the preliminary demonstration in UC3, the link between Scheduler and ECOIO has been explored. Scheduler is a state-of-the art tool for forecasting air traffic patterns, and ECOIO is an economic input-output model which allows to explore the broader economic impacts of changes in air travel. The demonstration therefore involves the connection between two different types of tools that were not connected via CPACS before, and that are operated by two different modelling teams. It also allows to demonstrate the preparation of output for the dashboard application.

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Here we zoom in on the MDAx view of coupling variables between these two models. The following figure shows in more detail the information that is exchanged between them.

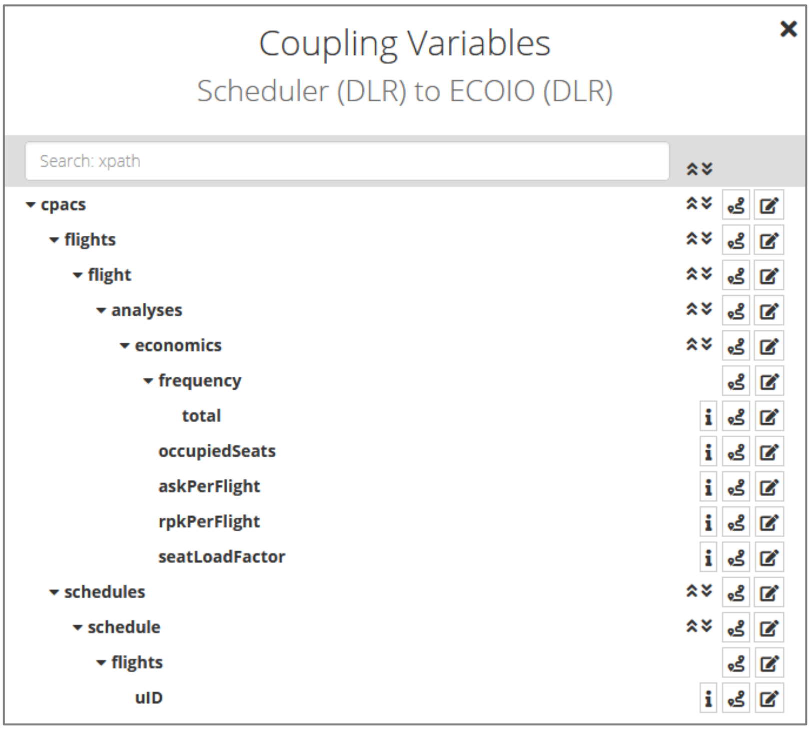

Figure 5-7: Link between Scheduler and ECOIO in MDAx

The CPACS and RCE status of the two tools were presented in Table 5 in Section 5.2.

The following steps have been undertaken to include the two models in CPACS and realise the RCE integration. Scheduler is a comprehensive tool for air-traffic forecast which utilizes multiple parameters including forecast models, flight frequencies and aircraft model information. One of the primary aims of Scheduler is to provide year-wise schedules focusing on departure and arrival airport pairs. Thus, a scheduler output is characterized by a particular forecast year. The output schedules include aircraft detail, origin and destinations airports, load factor and economic parameters such as askPerFlight, rpkPerFlight, seat-classes etc. (as shown in Figure 5-7).

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```xml
<header>···
</header>
<vehicles>···
</vehicles>
<schedules>···
</schedules>
<flights>
  <flight uID="flight1">
    <name>CJU-GMP</name>
    <vehicle>
      <vehicleUID>model_B737-800</vehicleUID>
      <weight>
        <loadFactor>0.90</loadFactor>
      </weight>
    </vehicle>
    <departure>
      <airportICAO>RKPC</airportICAO>
    </departure>
    <arrival>
      <airportICAO>RKSS</airportICAO>
    </arrival>
    <missions>
      <mission>
        <odGreatCircleDistance>450.82</odGreatCircleDistance>
      </mission>
    </missions>
    <analyses>
      <economics>
        <frequency>
          <total>14784</total>
        </frequency>
        <rpkPerFlight>55031.27</rpkPerFlight>
        <askPerFlight>61226.26</askPerFlight>
        <seatClass>
          <classType>08</classType>
        </seatClass>
      </economics>
    </analyses>
  </flight>
```

Figure 5-8: XML representation of Scheduler variables according to the CPACS schema containing the three major nodes vehicles, schedules and flights along with the header node. An expanded view of the flight node is shown as an example.

For the connection demonstration between Scheduler and ECOIO, a representative schedule for the year 2020 was selected. The Scheduler tool works primarily with three CPACS nodes, namely vehicles, flights and schedules. In the first step, the Scheduler output was converted to CPACS format via an internal Python script. Then, ECOIO extracts the required parameters from the previous output (CPACS.xml), focusing on economic parameters and finally adds the updated variables in studies node of the CPACS schema. Figure 5-8 shows an expanded view of the Scheduler flight node as per the CPACS schema.

For integrating the Scheduler output into ECOIO, the ECOIO model was extended with an import script in the statistical programming language R, in which the ECOIO model is also written. This import script reads the CPACS xml file from Scheduler and extracts all the schedule information for use in the ECOIO model. From the imported schedule data, the flight frequency information for each flight connection

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is used to calculate the total annual flight volume per country and the total annual flight volume worldwide. With this information, the economic effects can be estimated for each country and each schedule provided by Scheduler. For making the ECOIO output available for the dashboard application, an export script was written, also in R. This export script creates a CPACS output xml file that contains the estimated economic effects in the CPACS schema described in the preceding section.

For integrating the ECOIO model into RCE, a batch file was created containing the path to the R installation, the path to the main script file of ECOIO, and a command line for execution of the main script file. In the tool integration procedure in RCE, the path to this batch file was given as an execution command. In addition, a pre and a post execution script was added containing commands to store the input CPACS data in the RCE workflow as 'CPACS_in.xml' in the ECOIO data directory and to pass on the CPACS output file 'CPACS_out.xml' created by ECOIO.

An exemplary output of the ECOIO model based on the input of the scheduler model is presented in Figure 5-9. This figure shows preliminary results of the expected aviation-related employment in the EU member states in 2035. The basis for these estimates is the scheduler scenario UC3 DLRCON Y2035, which takes capacity restrictions at airports into account.

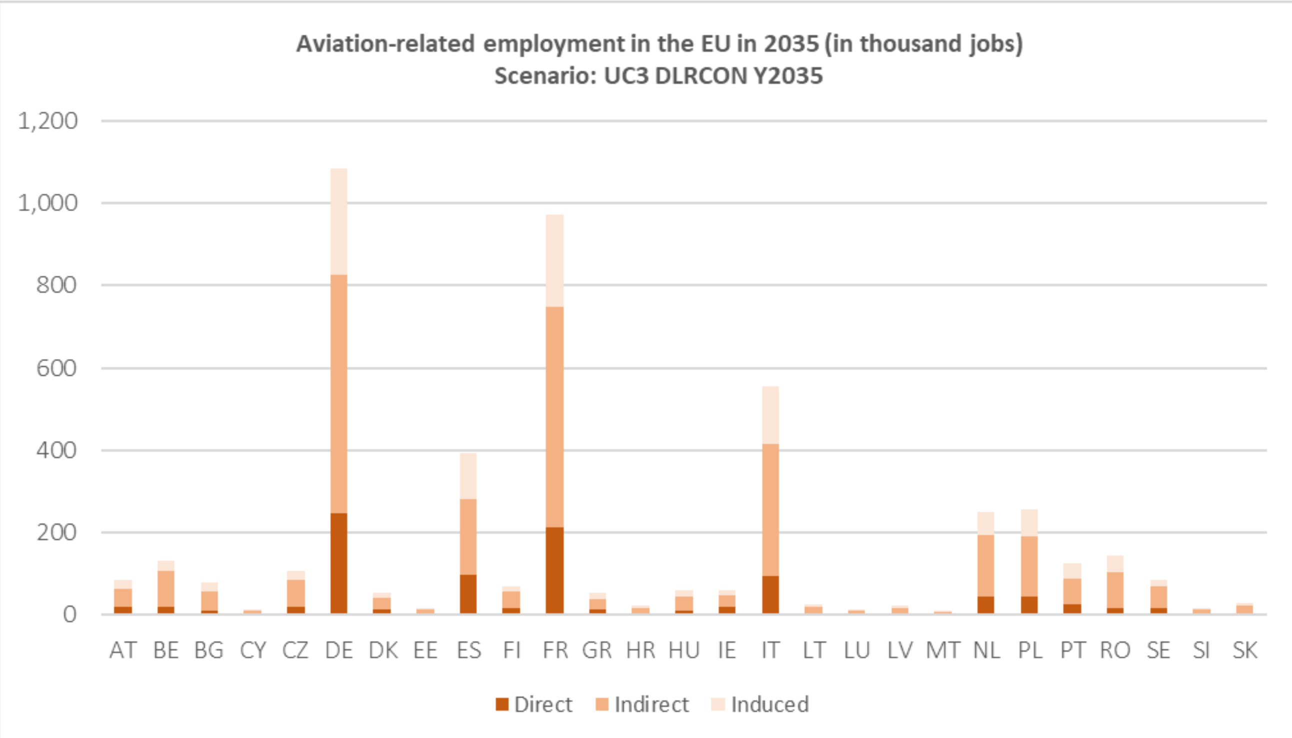

Figure 5-9: Example ECOIO output based on Scheduler input

This preliminary demonstration has been achieved thanks to the encapsulation of the models in CPACS as well as their individual integration in RCE allowing an accurate transfer of large quantity of information between Scheduler and ECOIO. The next step will be to finalize the CPACS data exchange across the remaining tools before running the UC3 studies.

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6. Conclusion

The Impact Monitor deliverable D5.3 provides a description of the operating scenarios and of the implementation process of the three demonstration Use Cases:

- UC1: Advanced propulsion system;
- UC2: Continuous descent operations;
- UC3: Sustainable aviation fuels.

In addition, it presented the different aspects of the implementation processes in the collaborative framework as well as an example of partial workflow execution for each UC.

This deliverable will be used as a reference document by each Use Case for the implementation and demonstration of the Impact Monitor framework and Dashboard Application.

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