

Assessing Advanced Propulsion Systems Using the Impact Monitor Framework [†]

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Abstract: Presented in this paper is the Impact Monitor framework and interactive Dashboard Application (DA) validated through a use case, focusing on investigating the viability and competitiveness of future propulsion architectures for next-generation aircraft concepts. This paper presents a novel collaborative framework for integrated aircraft-level assessments, focusing on secure, remote workflows that protect intellectual property (IP) while enabling comprehensive and automated analyses. The research addresses a key gap in the aerospace domain: the seamless matching and sizing of aircraft engines within an automated workflow that integrates multiple tools and facilitates real-time data exchanges. Specifically, thrust requirements are iteratively shared between aircraft and engine modeling environments for synchronized sizing. Subsequently, the fully defined aircraft data are transferred to other tools for trajectory analysis and emissions and other assessments. The Impact Monitor framework and Dashboard Application demonstrate improved efficiency and data security, promoting effective collaboration across institutions and industry partners.

Keywords: engine aircraft matching; advanced propulsion systems; MDO framework



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1. Introduction

The Impact Monitor Project, funded by the EU, aims to develop an impact assessment framework for European aviation. Coordinated by the German Aerospace Center (DLR), this initiative leverages digital technologies for collaborative engineering across the aviation sector, thereby streamlining the assessment processes at aircraft, airport, and system levels.

Recent research has focused on developing collaborative frameworks for aircraft-level assessments, addressing the need for efficient integration of engine manufacturer knowledge into preliminary aircraft design. These frameworks enable remote collaboration while protecting intellectual property [1]. Cloud-based approaches using microservices have shown significant time reduction in design iterations compared to traditional methods [2].

Automated workflows integrating disciplinary modules from different sites have been implemented for conceptual design and trade studies [3]. These collaborative design processes utilize centralized data formats and engineering frameworks to facilitate communication between analysis modules and partner organizations [4]. The frameworks allow for simultaneous optimization of airframe and subsystems, considering their synergies and impacts on overall aircraft performance. Case studies have demonstrated the effectiveness of these approaches in evaluating different subsystem architectures and mission scenarios and optimizing aircraft designs [4].

The aerospace industry increasingly relies on complex simulations and data exchanges across institutions to optimize aircraft design. However, protecting intellectual property while collaborating across multiple organizations remains a significant challenge. Current methodologies often involve manual or partially integrated processes, which are inefficient and prone to data inconsistencies. This research introduces a collaborative framework to address these challenges, emphasizing automation and secure workflows for aircraft and engine sizing and subsequent performance and environmental impact analyses. We discuss existing approaches and highlight the pressing need for an integrated and IP-protected solution.

In this study, the design of an airframe and an aeroengine will be used to demonstrate the benefits of automated collaborative optimization and how this approach compares to the traditional isolated design process that usually only allows a limited number of iterations and manual data exchanges between airframe and engine manufacturers.

A traditional joint airframe and engine design process is more aptly illustrated in Figure 1 and it entails the sequential design of the airframe and engine in an iterative loop until the requirements are met to satisfaction and one or more overall system objectives are minimized/maximized (e.g., specific fuel consumption, range, etc.). In particular, the aircraft design team will conduct their design studies using either an iteration of a physics-based engine model or a surrogate of it such as performance deck, produced by the engine design team. The latter will, in turn, have been obtained by designing the engine while relying on an iteration of the airframe thrust requirements. As mentioned before, in an industrial scenario, this process, while ripe for automation, is usually only partially automated—the airframe and engine design disciplines will themselves be automated while the transfer of information between the two will rarely be so. Often, it relies on both manually processed and controlled transfers of interface data (i.e., thrust requirements and engine performance deck), thus both limiting the pace at which design iterations can take place and their usability in automated design studies (e.g., as part of the design of experiments or system-level optimization studies) [5].

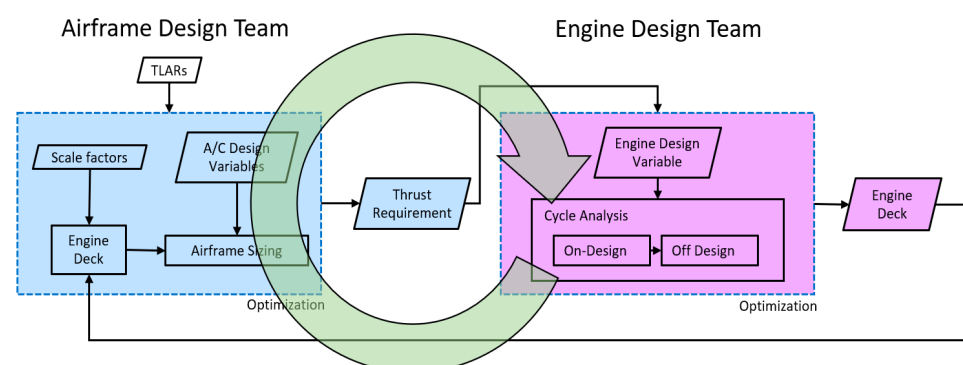


Figure 1. Airframe–engine matching design process.

In this research project, the entire process is fully automated, enabling the collaborative execution of tools hosted across different locations within a workflow, while ensuring the

protection of their intellectual property (IP). Further details have been discussed in next sections on how this framework and the Dashboard Application help to create and execute such workflows. The next section first describes the methodology of this use case. Next, the use case overview and results of the demonstration exercise are presented. The final section discusses the first conclusions that can be drawn from the exercise as well as the next steps that are still planned for this use case in the Impact Monitor Project.

2. Methodology

The proposed framework employs a distributed, automated workflow for aircraft-level assessments. It integrates multiple modeling and simulation tools, each operated remotely while maintaining IP protection through secure communication protocols and data handling techniques. The methodology consists of the following tools and processes for this use case.

This use case employs four tools from different organizations with specific capabilities combined to create an operational workflow which is developed with the MDAX (MDO Workflow Design Accelerator) tool [6], as illustrated in Figure 2. Tools/models involved in this use case are SUAVE (Aircraft Modelling Tool), TURBOMATCH (Engine Modelling Tool), DYNAMO (Trajectory Amendment for contrail avoidance), and AECCI (Aircraft Emissions and Contrails for Climate Impact).

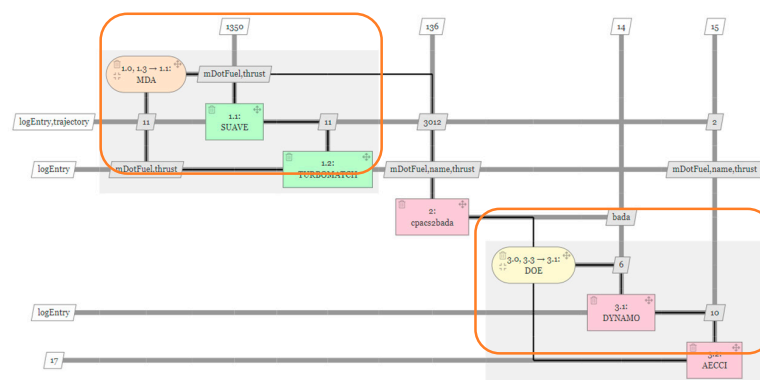


Figure 2. Computational workflow is created in MDAX.

Further, these tools are integrated and the workflow created in MDAX is replicated in a collaborative platform, RCE (Remote Component Environment) [7], which enables tool integration and execution using an Uplink connection for models/tools integrated anywhere in the world while protecting their IPs. Once all the tool integration and the workflows' connection with all data communication have been set up in the RCE, the workflow is ready to be executed.

The aim of the use case is to demonstrate the collaborative approach of the Impact Monitor framework with the integration of the four tools and the use of collaborative strategies enabled by CPACS (Common Parametric Aircraft Configuration Schema) and RCE, where CPACS [8] is the standardized way of data handling and communication among the tools which helps data transfers between various tools. In Figure 2, the two boxes depict two studies performed in this workflow:

- Study 1: Design Variables: fan pressure ratio, low pressure compressor ratio, high pressure compressor ratio, inlet airflow rate, aspect ratio, wing reference area.
- Study 2: Design Variables: cruise altitude, cruise speed/Mach no.

The workflow begins with preliminary aircraft and engine matching as mentioned in Figure 3. A dedicated tool simulates the thrust and performance characteristics required for different flight conditions. These data are automatically sent to the engine sizing model,

which adjusts the propulsion system parameters to meet these requirements. The refined engine specifications are returned to the aircraft model for further iteration. Once convergence is achieved, the complete aircraft data are shared with external analysis tools for trajectory simulations and emissions quantification. This use case highlights the framework's ability to manage complex, multi-disciplinary workflows across organizational boundaries.

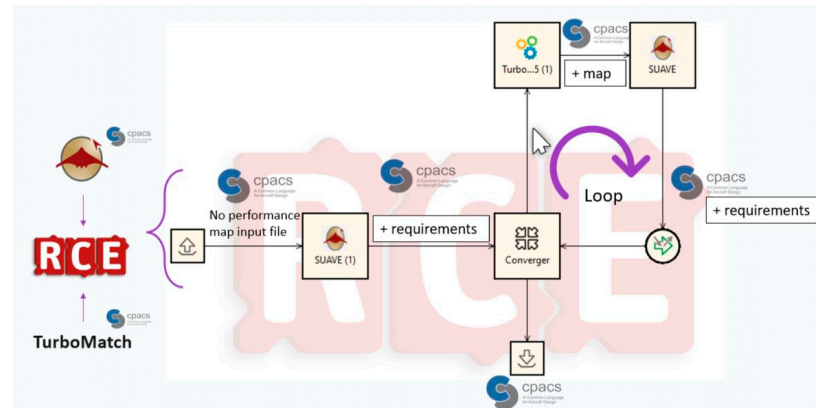


Figure 3. Computational workflow in Remote Connection Environment (RCE).

The detailed methodology for the tools involved and the process for Use Case 1 is outlined above. Figure 4 below illustrates the complete architecture for this use case, utilizing the Impact Monitor framework and Dashboard Application, which suggests that once a workflow is created and executed, the following steps are performed:

1. An iterative loop where thrust requirements are exchanged and refined between engine and aircraft models, ensuring optimal performance matching to generate one complete aircraft.
2. This CPACS file of generated aircraft is then sent to the CPACS2BADA converter which helps to convert CPACS file data to the standard BADA files which are used in some of the tools further in the use case.
3. These CPACS and BADA files are used as inputs for the remaining tools to perform trajectory and emission analyses and other studies.
4. Once all the analyses are performed using specific tools and the workflow is completed, the final output CPACS file is then uploaded to the cloud data storage.
5. Finally, the stored file can be accessed through the Dashboard Application for the various types of visualization and plots for the studies and further analyses.

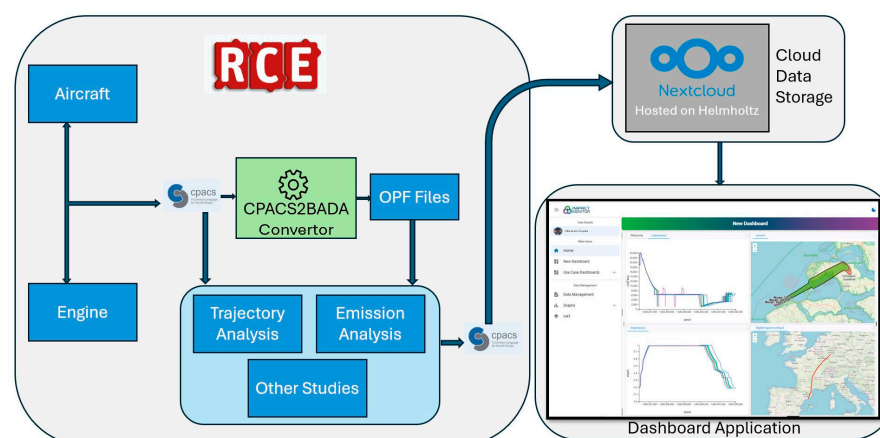


Figure 4. Architecture of use case workflow using Impact Monitor framework and Dashboard Application.

The Dashboard Application not only provides visualization for the data but also encompasses the capabilities of interactive and interlinked plots, data processing and tools to perform Multi-Object Optimization as well.

3. Use Case Implementation

In this section, the advanced propulsion systems' use case is implemented using the Impact Monitor framework and the results are presented. The use case involves the collaborative design and analysis of a single-aisle, tube-and-wing, low-wing configuration, with two wing-mounted turbofan engines, and conventional empennage. The mission considered for the baseline aircraft definition includes taxi-out, take-off, climb, cruise, descent, landing, and taxi-in, where fixed schedules for climb, cruise, and descent segments are employed.

As mentioned in the previous section, the computational workflow is divided into two studies. For study 1, iterative convergence between the airframe and engine design tools is performed using the fixed-point iteration method. During these iterations, two distinct local optimizations are conducted for airframe and engine sizing. The optimization problem formulations for the airframe and engine sizing are presented in Tables 1 and 2, respectively.

Table 1. Optimization formulation for airframe sizing.

Airframe Design Variables	Wing Area (m ²)	[120, 140]
	Aspect Ratio	[9, 12]
Top-Level Aircraft Requirements (TLARs)	Take-off Field Length (m)	≤2000
	Time to Climb (min)	≤25
	Approach Velocity (m/s)	
	Cruise Altitude (m)	≥11,000
	Cruise Mach Number	0.78
	Ceiling Altitude	≥12,000
	Maximum Operating Mach Number	0.82
	Range (nm)	≥4000
Objectives	Block Fuel (kg)	Minimize
	Maximum Take-off Weight (kg)	Minimize
Calculated Parameters	Take-off Thrust (N)	Calculated by airframe design team and passed to engine design team
	Second Segment OEI Thrust (N)	
	Climb Thrust (N)	
	Initial Cruise Altitude Thrust (N)	
	Cruise at 37,000 ft Thrust (N)	
	Ceiling OEI Thrust (N)	

Table 2. Optimization formulation for engine sizing.

Fan Pressure Ratio	[1.6, 2.0]
Low Pressure Compressor Ratio	[2.8, 3.2]
High Pressure Compressor Ratio	[9, 11]
Inlet Airflow Rate (kg/s)	[400, 600]

Table 2. *Cont.*

Thrust Requirements (T.R.)	Take-off Thrust (N)	Values provided by airframe design team
	Second Segment OEI Thrust (N)	
	Climb Thrust (N)	
	Initial Cruise Altitude Thrust (N)	
	Cruise at 37,000 ft Thrust (N)	
	Ceiling OEI Thrust (N)	
	Take-off Thrust (N)	
Objectives	Specific Fuel Consumption (kg/(N.s))	Minimize
	Engine Weight (kg)	Minimize
Calculated Parameters	Complete Engine Deck	Calculated by engine design team and passed to airframe design team

For airframe sizing, design variables (wing area and aspect ratio) and top-level aircraft requirements (as shown in Table 1) are utilized to calculate the engine thrust requirements, which are then transferred in a CPACS file to the engine sizing model using Uplink protocol. Two objectives, i.e., minimize block fuel and maximum take-off weight, are considered for the airframe sizing optimization.

On the other hand, for engine sizing, design variables (bypass ratio, fan pressure ratio, low and high compressor pressure ratio, and air mass flow rate) and engine thrust requirements (as shown in Table 2) are utilized to calculate the engine performance deck, which is transferred in a cpacs file to the airframe sizing model using the Uplink protocol. For engine sizing optimization problem, specific fuel consumption and engine weight are considered as minimization objects.

As mentioned in the previous section, the two tools employed for sizing airframe and engine cycle analysis are SUAVE and TURBOMATCH, respectively. The first step in the aircraft engine sizing loop is to define the basic aircraft and mission in SUAVE. Initially, the aircraft uses a low-fidelity engine performance model. This low-fidelity turbofan model calculates thrust and fuel consumption based on atmospheric conditions, throttle settings, and Mach number using simplified empirical relationships. It outputs thrust as a 3D vector and fuel flow rate, integrating these into the aircraft's performance framework. The model assumes ISA atmospheric conditions, a modern turbofan throttle ratio, and a constant specific heat ratio for quick, conceptual-level analyses. As part of the post-processing for the converged aircraft, a number of thrust requirements are calculated. The same is presented in Table 3 including the initial values:

Table 3. Calculated thrust requirements.

Phase	Altitude (m)	Mach Number	Calculated Thrust Requirements (N)
Takeoff	0	0.00	150,914
Second Segment OEI	122	0.22	86,255
Climb (2500 ft/min)	0	0.38	63,489
Initial Cruise Alt	10,439	0.76	25,051
Cruise (37,000 ft)	10,668	0.78	24,278
Service Ceiling	11,887	0.78	26,756
Ceiling OEI	7620	0.57	26,616

These requirements are stored in a CPACS file. When both SUAVE and TurboMatch are connected in RCE, the output file is transferred to TurboMatch automatically. TurboMatch reads the thrust requirements and creates an engine map for various altitude and Mach number combinations. The engine map includes information on Mach number, altitude, throttle ((actual thrust)/(maximum thrust at a given point)), thrust, and SFC. The output is again stored in a CPACS file and transferred back to SUAVE in RCE.

SUAVE extracts and converts the engine map from CPACS into a .csv file. With the engine map available, SUAVE's performance calculation logic is updated to a surrogate model-based engine simulation. This approach allows thrust and fuel consumption to be predicted using the pre-loaded CSV file, leveraging a surrogate model (e.g., linear, Gaussian Process, KNN, or SVR) to approximate engine performance metrics like thrust and specific fuel consumption (SFC). The model dynamically evaluates these metrics under varying conditions and blends data for extended throttle ranges if needed.

Using this updated logic, the aircraft is sized again. Based on the new calculations, the thrust requirements are updated and transferred to TurboMatch. This process is repeated iteratively until the thrust requirements stabilize (convergence is reached). At this stage, it is assumed that the provided engine map is highly accurate, requiring no further scaling of engine performance in SUAVE. Therefore, to finalize the calibration of the aircraft, only its aerodynamic performance is adjusted. With the updated aerodynamics, the low-fidelity engine performance is recalculated, and the loop is restarted. This process continues until the aircraft and engine meet the desired performance criteria. The results of the optimized engine and airframe are shown in Figures 5–8.

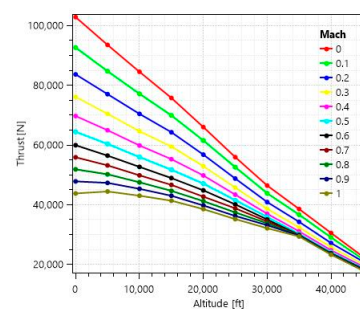


Figure 5. Engine deck performance (thrust vs. altitude).

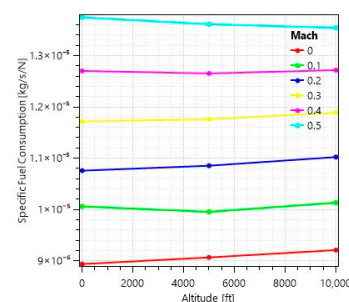


Figure 6. Engine deck performance (SFC vs. altitude).

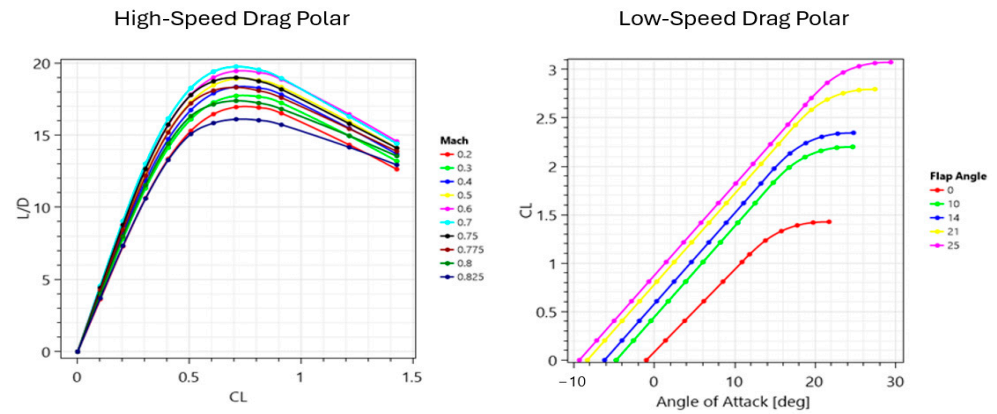


Figure 7. High-speed and low-speed drag polars.

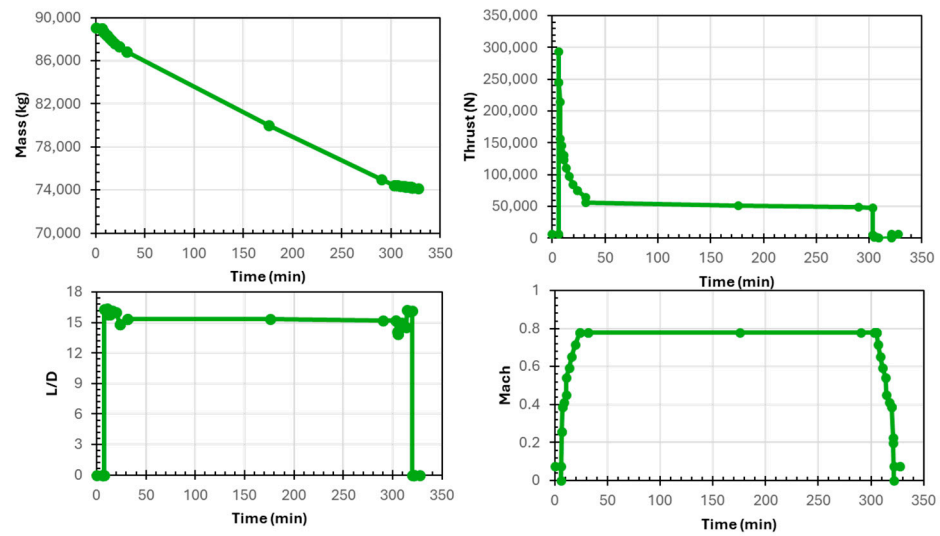


Figure 8. Mission performance.

Once the convergence between airframe and engine design teams is achieved, the optimized aircraft can be utilized for study 2, where 4D trajectory analysis is performed for emissions assessment. Here, the cpacs2bada convertor is employed which generates BADA .opf and .apf files from the cpacs file obtained from study 1. The results from study 2 are shown in Figure 9.

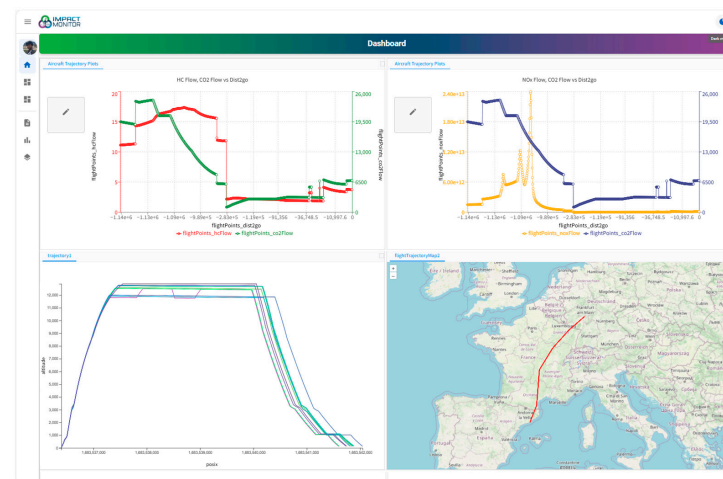


Figure 9. Four-dimensional trajectory analysis illustrating 16 variations and emissions assessment.

The Impact Monitor framework enables the collaborative design of airframe with advanced propulsion systems. Key findings from the presented use case include efficiency gains, data security, scalability and flexibility, and trajectory and emissions analysis. Compared to a manual approach which takes approximately one week to complete manual iterations between the airframe and engine matching, the proposed automated approach using the collaborative Impact Monitor framework takes around 35 min on average to complete the workflow.

4. Summary and Conclusions

This paper introduces a secure, automated, and collaborative Impact Monitor framework for various levels including aircraft-level assessments, addressing critical research gaps in engine–aircraft integration and cross-institutional cooperation. By automating data exchanges and protecting IP, the framework enhances efficiency and fosters innovation. Future work will focus on expanding the framework’s capabilities to support additional tools and exploring machine learning techniques for further optimization.

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