ICAS 2021 SHANGHAI
International Council of the Aeronautical Sciences
32nd Congress of the International Council of the Aeronautical Sciences
September 6-10, 2021
Pudong Shangri-La, Shanghai, China

THE CAPABILITIES OF AUTOMATION OF MDAO PROBLEM STATEMENT AT COLLABORATIVE CONCEPTUAL DESIGN OF THE PROPULSION SYSTEM USING OPEN SOURCE SOFTWARE TOOLS

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Abstract

The paper presents the results of a study of various possibilities for automation of MDAO problem statement at conceptual design of the propulsion system of a commercial aircraft. Special open source software tools such as KADMOS (a software tool based on the use of graphs to formalize the formulation of MDAO tasks), CMDOWS (a special format for describing MDAO tasks) and VISTOMS (a software tool for visualizing the MDAO task formulation process) are used for visualization, control and automation of the MDAO problem statement formulation process. To directly solve the MDAO tasks, an open source software integration environment RCE is used.

Keywords: MDAO, problem statement, automation, open source code, visualization, integration environment

1. Introduction

Conceptual design of Propulsion System (PS) using Multidisciplinary analysis and Optimization (MDAO) approach requires the collaborative efforts of heterogeneous team of experts from the different disciplinary fields (so called competence centers) as well as integrating simulation tools and knowledge base.

Successful materialization of such an integrated MDAO system depends strongly on the effectiveness of the implemented integration system including, first of all, its flexibility, availability and opportunity to operate in distributed environment on the remote machines with protection of intellectual property. All these requirements are fully satisfied by the DLR's software RCE (Remote Component Environment) [1]. The RCE is widely used in the European AGILE and AGILE 4.0 projects dedicated to the development of a new generation of MDAO systems for the entire cycle of collaborative project development [2,3].

RCE has several advantages that help to design MDAO systems. First of all RCE is open-source framework. It has useful built-in components for postoptimisation and parametric analysis, handling data files, design of experiments, optimization. In RCE 8 common used optimisation methods are providied which are included in open-sourced complex Dakota – Design Analysis Kit for Optimization and Terascale Applications, developed by Sandia National Laboratories [3]. RCE supplies user-friendly graphical user interface (GUI) for creation of complex MDAO systems. Python interpreter inside allow users to extend the functionality in the desired way by executing user-defined Python scripts.

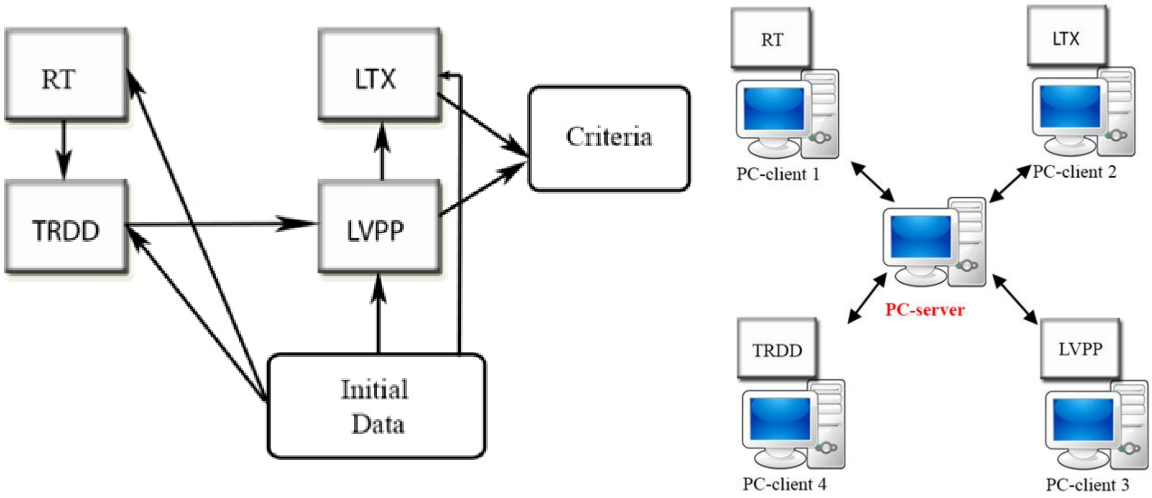
In terms of MDAO system development, RCE represents the second, execution phase of the design process. First phase, formulation, in practice takes 60-80% of all the available project time. To significantly reduce this time, open-source graph-based tool KADMOS was developed during AGILE project and also considered and applied in the activity. Visualization package VISTOMS was also used to generate the necessary visualizations of MDAO system development.

Connection between formulation phase (KADMOS) and execution phase (RCE) is provided by the CMDOWS file which contains full specification of MDAO system.

2. Problem statement

The goal of the project was to use the all above mentioned packages for finding optimal concept of the long-haul airplane.

Four distributed tools were integrated in the project: two engine tools for engine performance modeling (RT, TRDD), two tools for aircraft mission performance modelling (LTX, LVPP). These tools were located on the different PCs in one local network. The data flow between tools is presented on the Figure 1a. Central data scheme was considered to integrate all tools in one workflow (Figure 1b).



a) b)

Figure 1 - a) data exchange scheme (a) and server-client network for RCE implementation (b).

Optimization task was to find Pareto-optimal set of solutions for the following multidisciplinary analysis and decision making. Four parameters were specified as design variables: take-off wing loading, take-off thrust loading, cruise fun pressure ratio, turbine entry temperature. Three parameters were specified as objective functions: cruise range, balanced field length, fuel efficiency.

3. Tool Integration, workflow construction and execution in RCE

RCE – is the PIDO-platform where the workflow is created manually by the integrator via integration tools as a black-boxes, adding built-in elements like optimisers, convergers, DOEs. If tools are located in distributed PCs than integration is conducted in two possible ways - via a local network or the internet. The tools for integration in RCE are required only to be executable from the command line and be done in non-interactive mode.

All 4 tools were successfully integrated in RCE workflow. Parametric study was conducted and some results are shown on the Figure 2.

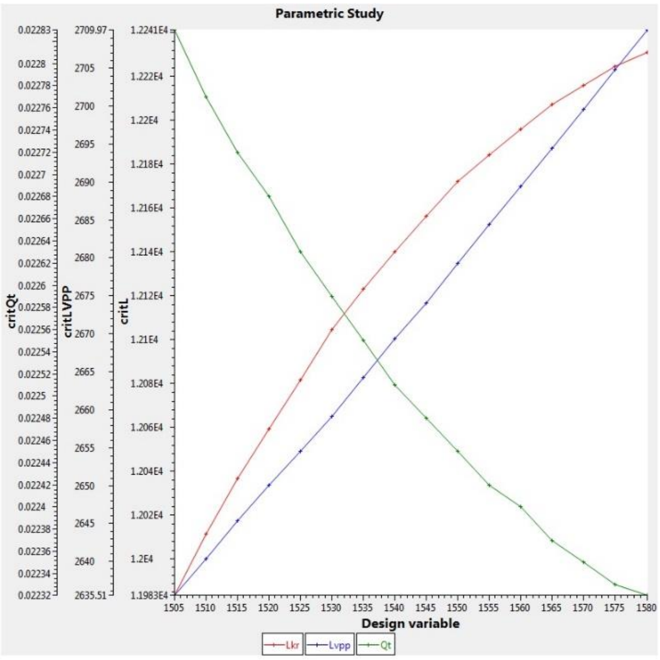


Figure 2 - Parametric study in RCE.

4. KADMOS, VISTOMS, CMDOWS software tools

KADMOS is the system of graph-based methods for automation of MDAO design formulation phase. KADMOS supports all the internal stages of formulation phase of the design process including collection information about connections between disciplinary tools in special repository, definition of design variables/constraints/objectives and formulation of solution strategy using graph theory for creation of the final workflow. KADMOS is the open-source Python package. It doesn't have its own graphical user interface and VISTOMS can be used as an effective environment to review, debug and examine all the stages of formulation phase.
KADMOS creates graphs on each stage of the design process.
On the first stage each tool in the repository is described by the base XML-files, containing their input/output information. Repository Connectivity Graph(RCG) is created automatically which describes the connections between disciplinary tools.
Three different types of visualization are presented in VISTOMS:
- using Extended Design Structure Matrix XDSM;
- using Edge Bundling Diagram;
- using Sankey Diagram.

XDSM [7] – is the extension of the widely known format of connection representation in the form of Design Structure Matrix DSM. In such extended format it is possible not only to overview the connections between tools but also the process to be executed.
XDSM representation of RCG, which was obtained in VISTOMS, is shown on the Figure 3.

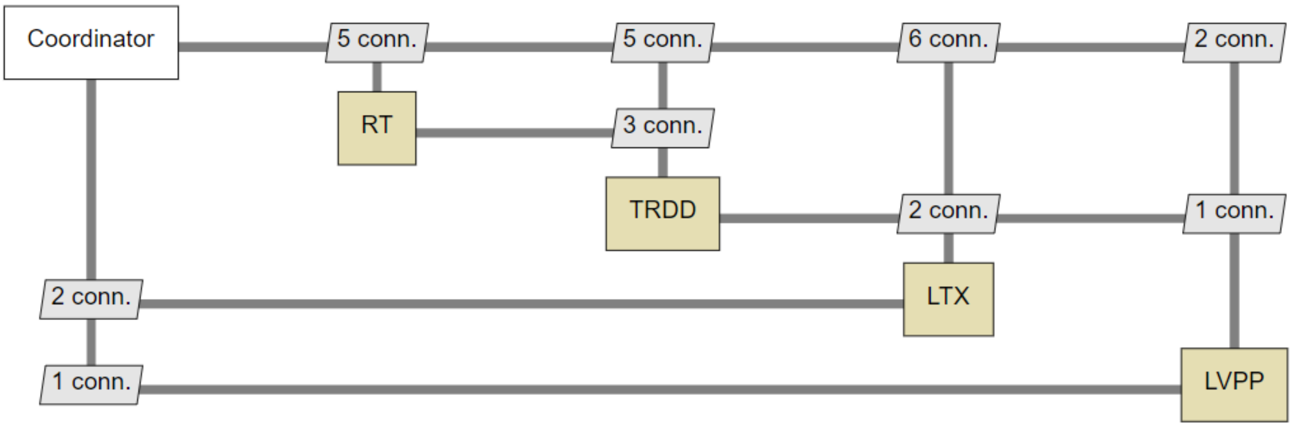


Figure 3 - XDSM-representation of RCG.

The discipline tools are positioned on the diagonal. Iterative components (e.g. optimizers and convergers) will have have an elliptical shape, rectangles are non-iterative components (e.g. disciplinary analyses and mathematical relations). Data dependencies between components are denoted by off-diagonal parallelograms, grey-colored shapes indicate couplings and white-colored ones indicate system I/Os. The data dependencies should be read in a clockwise direction. Data links between components are accentuated with thick grey lines. Finally, the execution process of the MDAO solution strategy is indicated using numbers inside the blocks in combination with thin black process connection lines (see Fig.9).
On the initial stage, when tools are already added to the graph, but the sequence of their execution is not defined yet, the direct and feedback connections are not important. But after all the elements will be sequenced, these connections will specify execution sequence. The coordinator node provides the system-level inputs and collects system-level outputs. It is like an external world and is the main control function of all the system. It means that any variable, which is provided by the Coordinator, is provided by none of the other tool in the system.
The list of all variables provided and obtained by the block, may be overviewed by clicking on its connection (Figure 4).

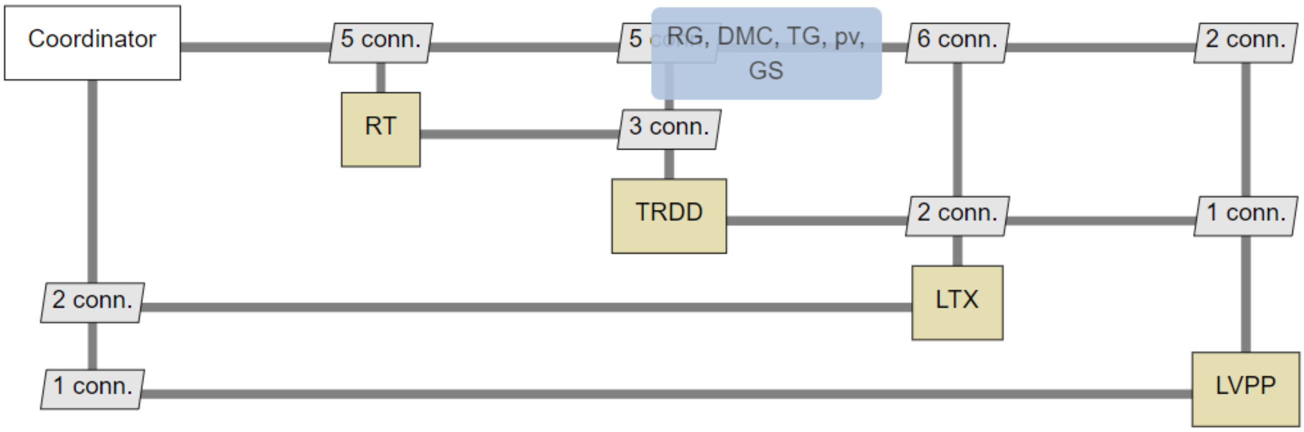


Figure 4 - Data exchange in XDSM.

Two other types of visualization – Edge Bundling Diagram and Sankey Diagram are shown on Figure 5 and Figure 6 respectively.

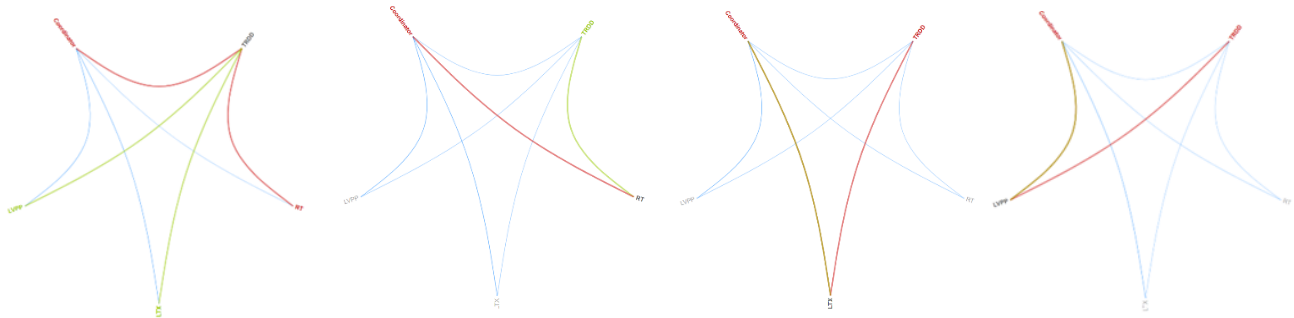


Figure 5 - Edge Bundling Diagram representation.

On Figure 5 thickness of the arrow represents the number of connections between tools.

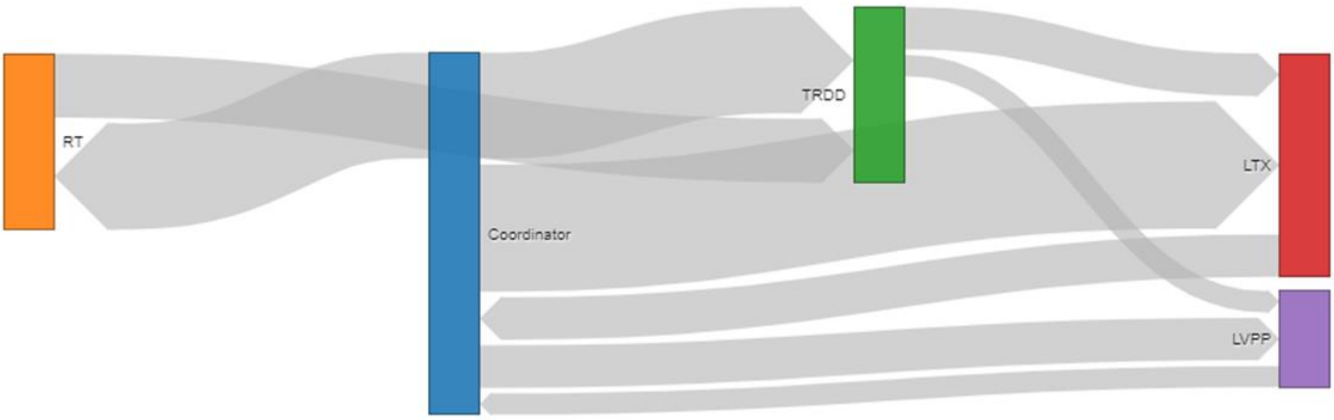


Figure 6 - Sankey Diagram representation.

More information also may be included in VISTOMS to the description of the system such as license, developer, execution accuracy, accuracy level, results verification and other.

Execution sequence of all the tools may be defined automatically.

Adding tool in the system, several important investigation may be conducted with the obtained graph (especially it is important if number of tools and connections is large) including graph inspection and graph manipulation. It is possible to get and analyze data model as tree or list, to specify initial values of the parameters (Figure 7), to generate XML-files and so on.

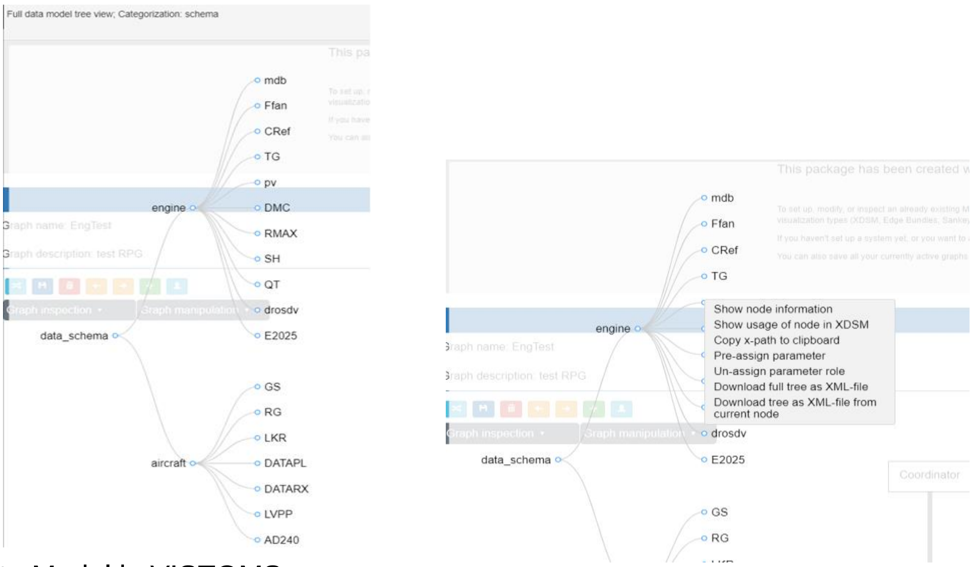


Figure 7 - Data Model in VISTOMS.

The second stage of the process is MDAO problem definition when Fundamental Problem Graph (FPG) is generated in KADMOS. All the unnecessary variables and tools should be automatically removed from the RCG (according to the selected built-in method) and main design variables, constraints and objectives should be specified (see Figure 8).

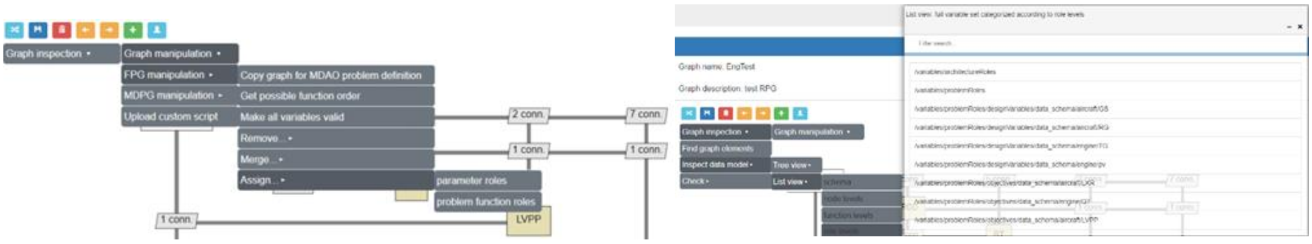


Figure 8 - Assigning problem roles of parameters.

The third stage of the process is defining the solution strategy when two types of graphs are generated – MDAO data graph (MDG) and MDAO process graph (MPG). MDG is graph that stores data exchanged by the executable blocks - both tools and architecture blocks (such as DOE, optimizers, convergers) - and other elements of the system. DAO Process Graph (MPG) contains only executable blocks from the MDG and the specification of their execution order. Standard number of solution strategies is realized in KADMOS - Unconverged MDA, Converged MDA, Individual Discipline Feasible, Unconverged Optimization, Unconverged Design of Experiments (DOE), Converged Design of Experiments (DOE), Collaborative Optimization, Bilevel Integrated Systems Synthesis Bliss-2000.
MDG with DOE solution strategy is shown on the Figure 9.

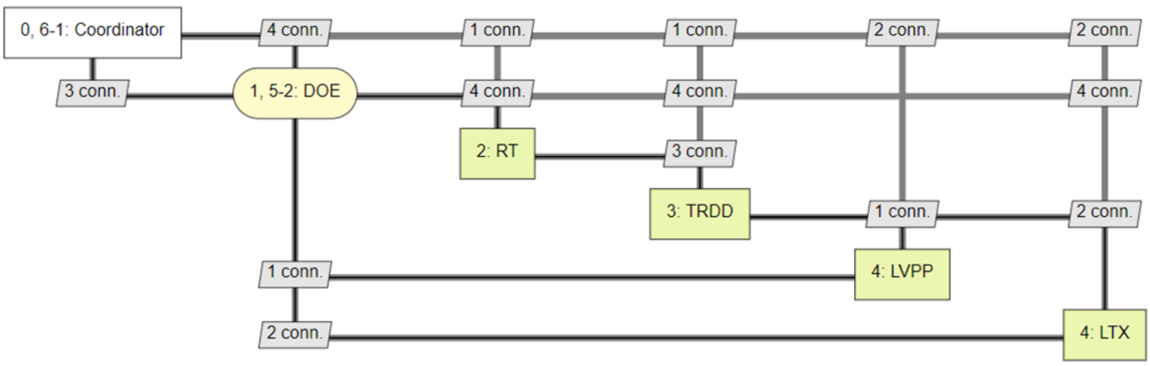


Figure 9 - MDG with DOE solution strategy.

After all the stages are realized and visualized the main goal is to get the executable workflow which could be run on the PIDO platform automatically. This become possible by using special format interpretable by the PIDO-platform (RCE). As such a format CMDOWS may be considered and it is translated to the PIDO-platforms through the special parser. CMDOWS – Common MDO workflow schema – is the open-sourced format to store information about MDAO system in the special format (CMDOWS xml-files). This is information about tools, data exchange between them, execution order, solution strategies and so on.
In VISTOMS each KADMOS graph may be saved, loaded and manually modified in CMDOWS-file.
DOE architecture is chosen for testing via CMDOWS parser in RCE. Workflow as a result of parsing is shown on Figure 10.

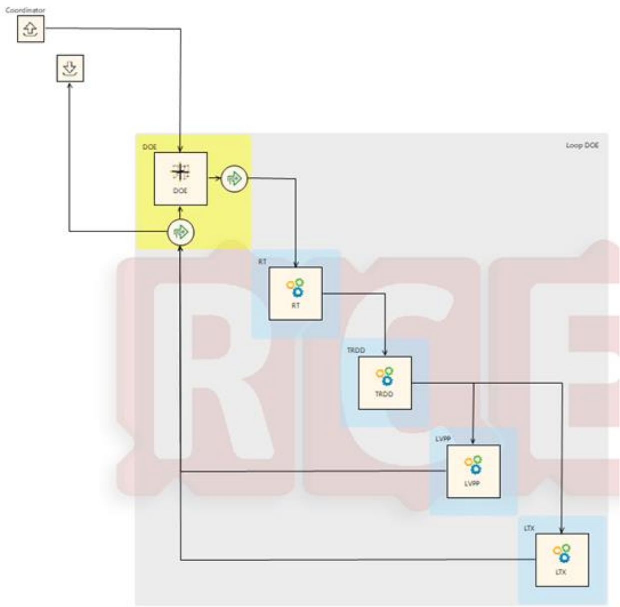


Figure 10 - The RCE workflow for implementation of DOE, received in VISTOMS as a CMDOWS file.

It should be mentioned that all the tools were previously integrated in RCE.

5. Conclusion

The capabilities of using open software tools VISTOMS, CMDOWS and KADMOS for automation of the formulation of the MDAO problem at the conceptual design of the propulsion system are considered. The tools allow to visualize the stages of the MDAO problem tatetment, conduct a graph-oriented analysis of the relationships between models data, and create and save a workflow in a special file for solving MDAO tasks in the RCE.

Based on the example of problem statement for propulsion system multidisciplinary optimization at conceptual design in the VISTOMS visualization environment, XML files of input data for 4 models used were created, all 3 stages of MDAO problem statement were implemented: creating a model repository, generating initial information for solving the MDAO problem and formulating a solution strategy in the form of DOE.

The results showed that modern open software tools VISTOMS, CMDOWS and KADMOS can be successfully used at the conceptual design stage to accelerate the formulation of MDAO tasks.

At the next stage of the work, it is planned to consider the use of open source tools capabilities for more complex optimization systems, including feedback on parameters and iterative processes.

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7. Copyright Statement

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