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A Simulation Model for Experimental Small Jet UAV with Model Based Design Approach

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ABSTRACT

Model Based Design (MBD) is a development method that integrates the design, implementation, and verification of any system, and has grown in popularity in recent years. This method makes the simulation the main element of the development process, allowing continuous prototyping. In this article, the simulation model of small jet DEHA UAV is realized by using model-based design tools. Within the scope of the study, the life cycle of model-based design for the aircraft includes the creation of requirements, system architecture and detail design models. Thanks to the model-based design life cycle, traceability is provided from system requirements to detailed design. As a result, by using model-based design tools, the design cycle of a complex system such as aircraft is maintained quite easily.

INTRODUCTION

Model Based Design is a development method that handles the entire development process from the determination of requirements to design, implementation and testing around the system model. The method is interpreted with different nuances in different areas and different standards are used for modeling [M.Canpolat and U.Drak, 2012]. In this article, an aircraft simulation model has been implemented. The life cycle of the model-based design realized in this study is shown in Figure 1.

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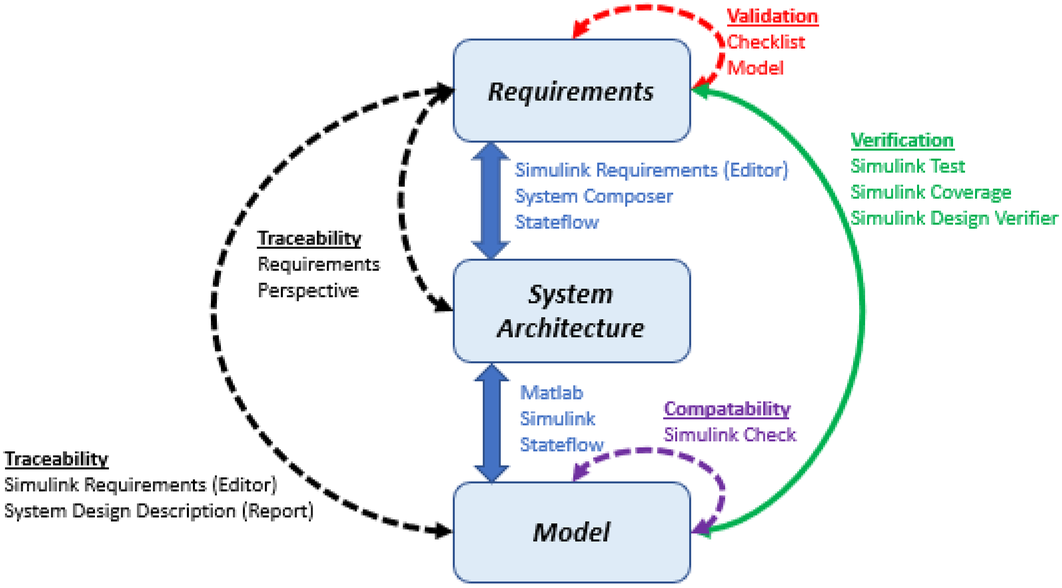

Figure 1: Model-Based Design Life Cycle

Model-based design includes model-based systems engineering, model and testing processes. MATLAB / SIMULINK tools are used as a model-based design environment. In this study, the simulation model of the small jet DEHA UAV is shown in Figure 2.

Figure 2: DEHA UAV

MODEL BASED SYSTEM ENGINEERING

Model-based design starts with model-based system engineering studies. Model-based systems engineering is an approach to successfully implementing systems driven by a model that reflects multiple perspectives of the system, contains a consistent set of views. Model-based system engineering covers the requirements and system architecture stages of model-based design processes.

Requirement in Model Based Systems Engineering

Requirements management is an iterative process that continues throughout the model-based systems engineering activities of the study. Requirements management covers the processes of defining requirements, validation, traceability and verification of requirements. Simulink Requirements, which are used to create, manage and analyze requirements in the MATLAB / Simulink environment, are an important tool needed in the development process of requirements.

In this study, the management of the requirements is done with the Requirements Editor within the Simulink Requirements. All requirements are stored in a single requirement set, and system requirements are managed through this set. The Simulink Requirements Editor screen, where the requirements are created, is shown in Figure 3.

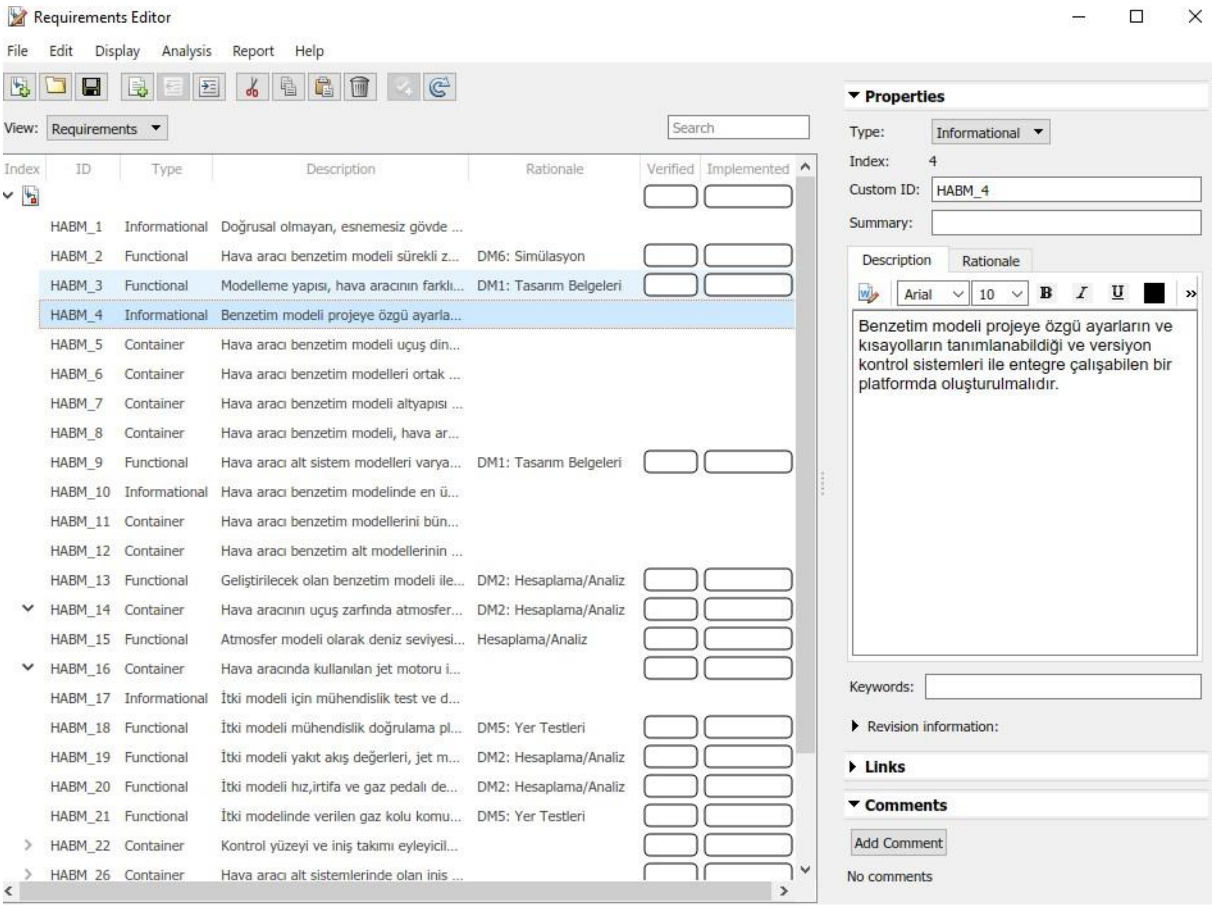

Figure 3: Simulink Requirements Editor Screen

Traceability in requirements defines the whole life process of requirements. Traceability is ensured by the integration of requirements into models. Traceability of the requirements is very important for verifying the requirements. The model in which the requirements are integrated is shown in Figure 4.

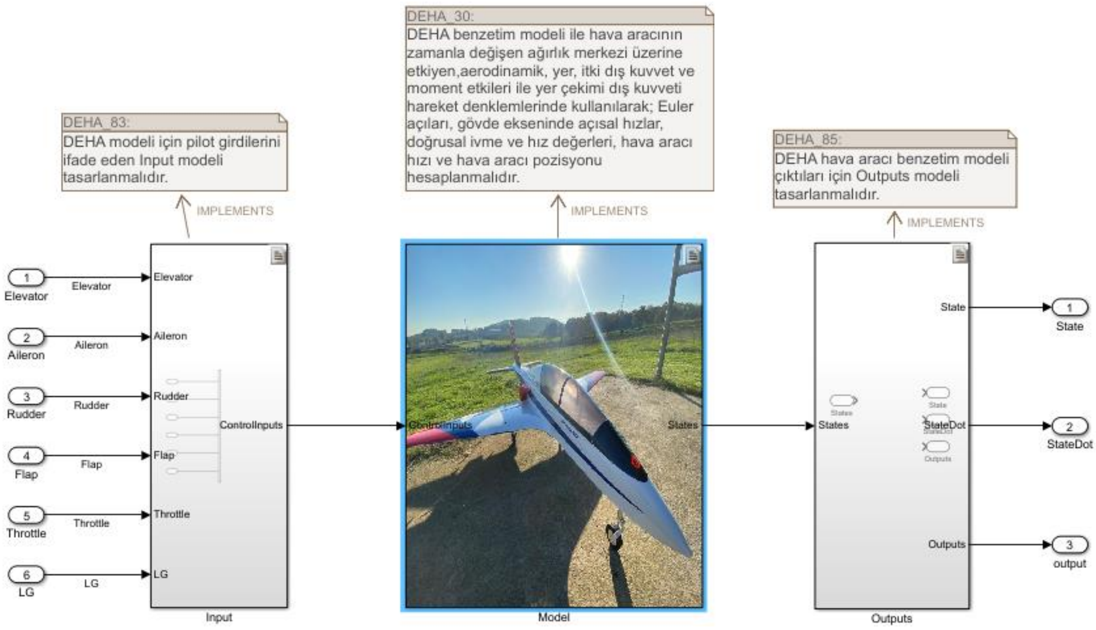

Figure 4: Requirements Integration in Simulink

Models developed at the design stage are tested to verify the requirements. If the features required to be in the system in the test results are provided as specified in the requirements, the requirements are considered verified. The Simulink Requirements Editor allows working with Simulink Test tools to define, traceability, and validate requirements [Albert R. P.,2021]. Through the editor, an automatic report is created in which all the information related to the requirement is collected in the model- based design process. An example of the content of the automatic report created within the scope of this study is shown in Figure 5.

8

Requirement Type Container

ID HABM_8

Description

Hava aracı benzetim modeli, hava aracı modelini, alt sistem modellerinin kütüphanesini ve model verilerinin saklandığı veri sözlüğünü içeren bir kurgu ile oluşturulmalıdır.

Change Information No change issue detected.

9

Requirement Type Functional

ID HABM_9

Description

Hava aracı alt sistem modelleri varyant şeklinde oluşturulmalıdır.

Rationale

DM1: Tasarım Belgeleri

Change Information No change issue detected.

Implementation Status

Total: 1, Implemented: 0, Justified: 0, None: 1

Verification Status

Total: 1, Passed: 0, Justified: 0, Failed: 0, Unexecuted: 0, None: 1

▸ 10

Figure 5: An Example of Automatic Report

System Architecture in Model Based Systems Engineering

System architecture is a conceptual model that defines the structure, behavior and formality of a system. Within the scope of this study, system architecture is created using the System Composer tool. System Composer, in the model-based engineering and software design process; is a MATLAB / Simulink tool used to determine, analyze and define system architecture [System Composer,2021]. While creating the architecture with System Composer, high-level requirements are also linked to the architecture, and this architecture can then be converted and simulated into the Simulink model. Thus, it is aimed to create detailed models in Simulink environment by taking the system architectures established here as reference.

Graphical modeling is very important when creating the system architecture. There are three main reasons why graphical modeling is needed.

- Systems consist of highly complex components. An example of these systems is air vehicles, which is also the focus of this thesis study.
- Cooperation between system engineers and different design teams is very difficult to agree on the system requirements and system architecture, which are the outputs of system engineering activities.
- Communication between the teams formed for the realization of the systems is very important. This situation is quite difficult in complex systems.

Model structure consists of “Actuator”, “Landing Gear”, “Atmosphere”, “Aerodynamics”, “Propulsion”, “Jet_Mass_Properties”, “EOM” components. The Model structure in which the nonlinear simulation model will be realized for the DEHA aircraft gives the output States. With these outputs, it is envisaged that various analyzes and simulations will be made for the aircraft. Model structure system architecture created in the System Composer tool is shown in Figure 6. The system architecture created forms the basis of the simulation model of the aircraft.

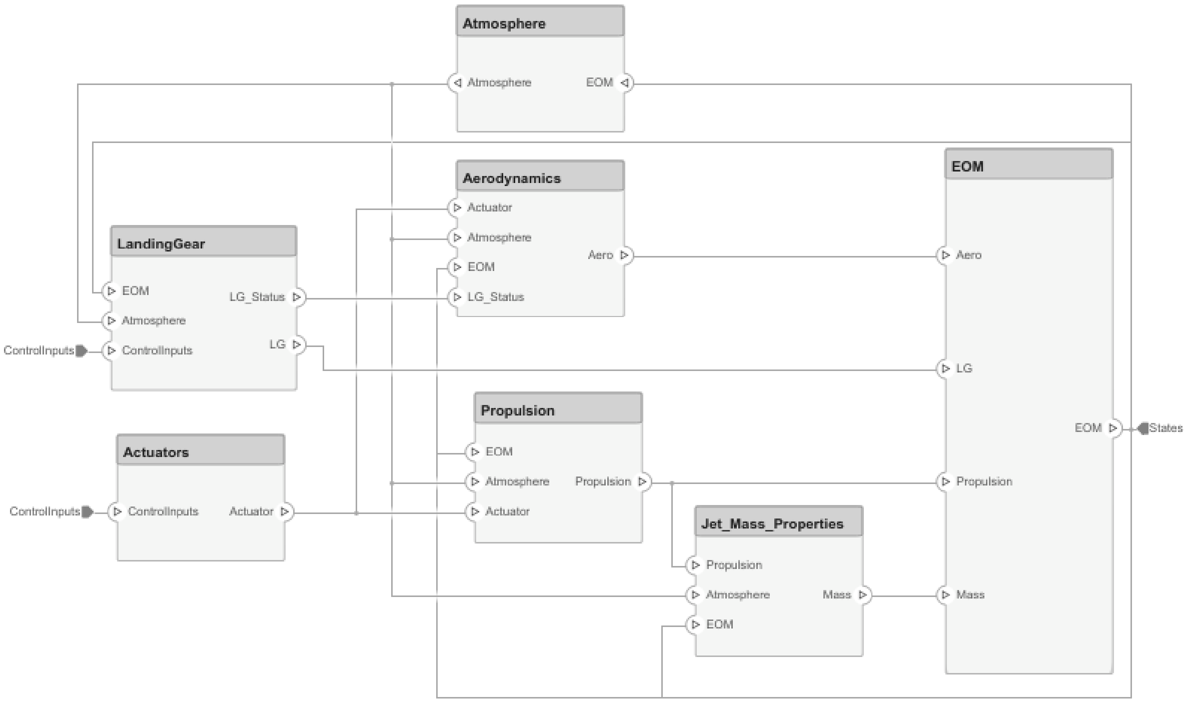

Figure 6: Model Structure System Architecture in Simulink Composer

MODEL

Model studies performed in order to use the model-based design method determined for the aircraft simulation model developed in this study effectively are explained in this section. For the development of the model, the Simulink Project structure was preferred because it includes more than one model, the project-specific settings are defined and it can work integrated with version control systems. Simulink Project is a tool that hosts more than one model file, makes it easy to control file directories, maintain all the required files of the project in one place and allow model version control [Simulink Projects,2021]. Managing all the MATLAB and Simulink design files, requirements, reports, test vectors, and code used in the project in one place helps the developer keep things running smoothly. The architecture of the project developed in the Simulink Project environment is shown in Figure 7.

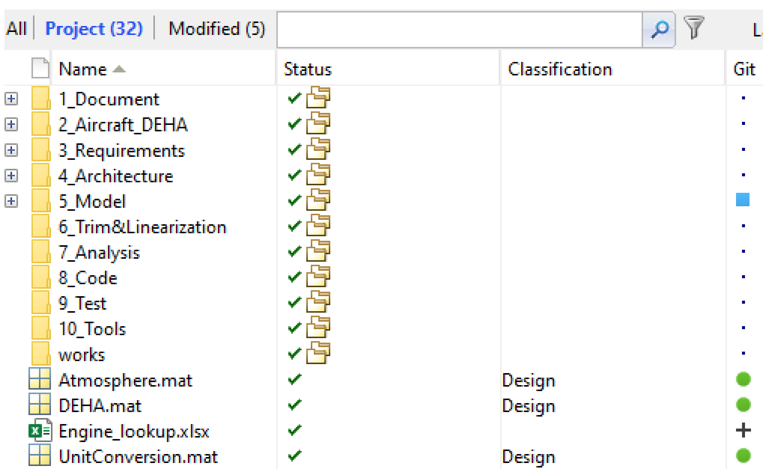

Figure 7: Model Structure in Simulink Project

The models in the study are managed by the "DEHA_model.slx" model that creates the aircraft model, the "DEHA_lib.slx" model, the library of the subsystem models that make up this model, and the "DEHA_dic.sldd" data dictionary where the model data is stored.

The "DEHA_model.slx" model is the main simulation model combining sub-models for the aircraft. The simulation model created by preserving the structure in the system architecture is shown in the Figure 8.

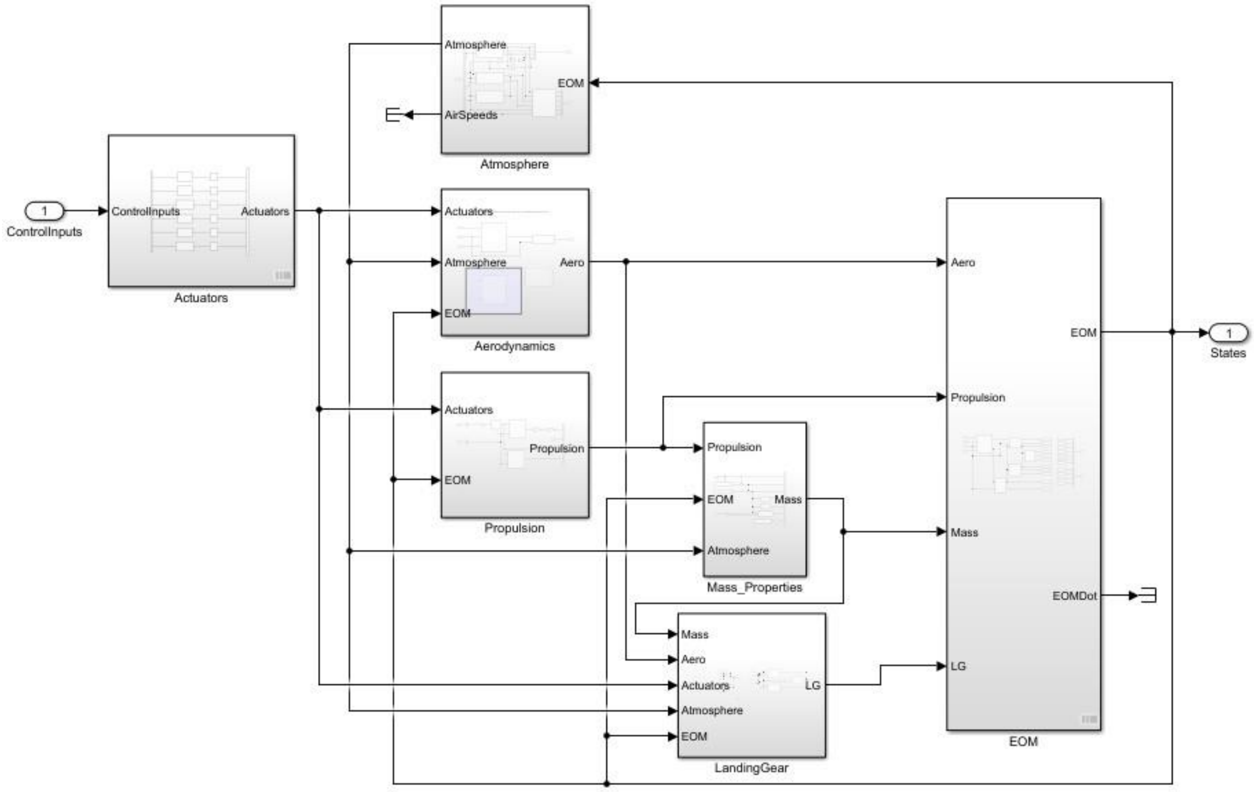

Figure 8: DEHA_model.slx in Simulink

The "DEHA_lib.slx" model creates the library files of aircraft subsystems (Actuator, Engine, Input, Mass and Aerodynamics). The Simulink library view is shown in Figure 9. While creating test models in model validation studies, feeding the model created in the library before is the most efficient way for the process. Due to the library model, test results can be obtained by giving only entries.

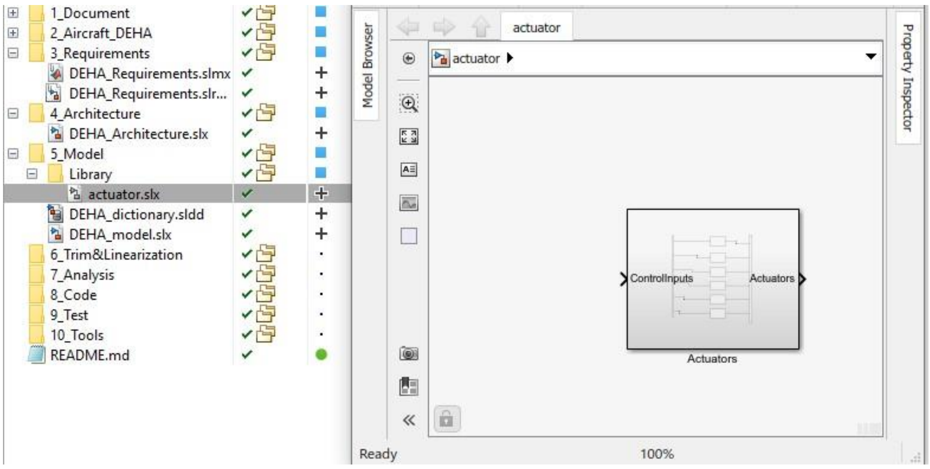

Figure 9: An Example of Library Model in Simulink

The "DEHA_dic.sldd" model stores the data required to be subject to version control, considering the use and change while managing the data of the aircraft. For example, there are signal bus of the inputs and outputs of the subsystems in the data dictionary. The signal bus used in the DEHA model are shown in Figure10.

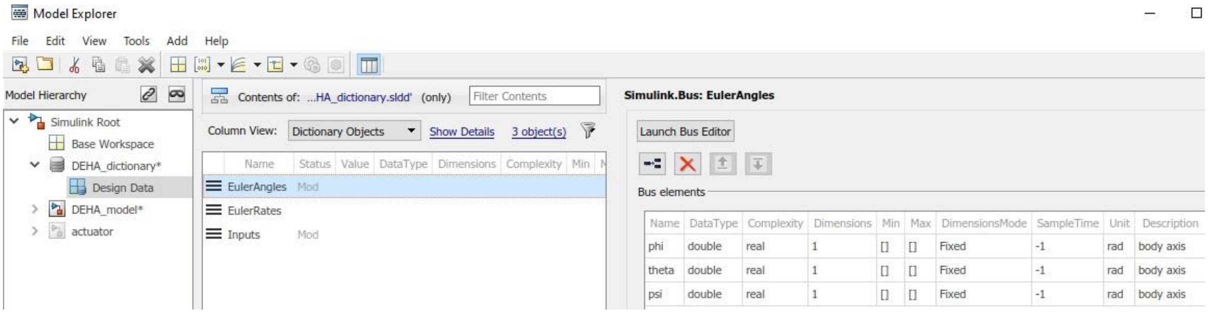

Figure 10: An Example of Dictionary in Simulink

Within the scope of this study, modeling and validation of each sub-model shown in Figure 8 was done. In this paper, only the model and analysis results of the aerodynamic model are described as an example. In the "Aerodynamics" sub-model, the forces and moments in the aerodynamic reference axis are calculated using the tables created in the aerodynamics database, and their conversion to the forces and moments in the body axis is made. The aircraft aerodynamics model is shown in Figure 11.

Figure 11: DEHA Aircraft Aerodynamics Model

The aircraft aerodynamic database was obtained using DATCOM software [Fink. R., 1978]. The aircraft created in DATCOM software is defined in wing, vertical tail and horizontal tail configuration. The sketch resulting from the definition of the aircraft in the DATCOM software is shown in Figure 12.

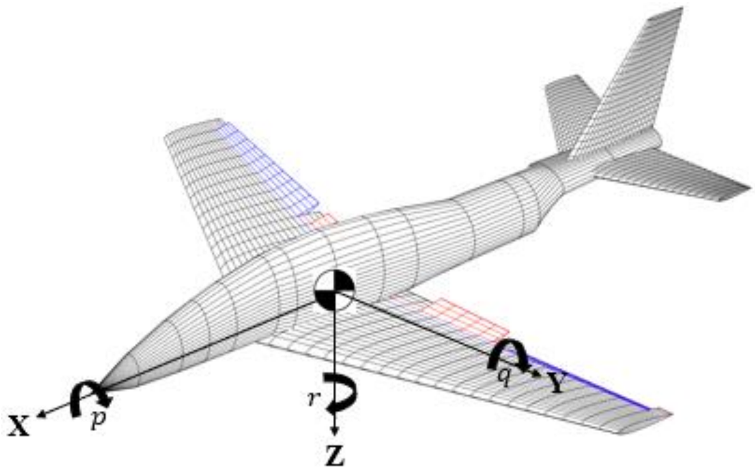

Figure 12: DEHA UAV DATCOM Modeling

A three-dimensional plotting code has been developed to check the accuracy of the aircraft's definition in DATCOM. Thanks to this code, the three-dimensional design of the aircraft can be compared with the aircraft defined in the DATCOM software. The comparison result is shown in Figure 13.

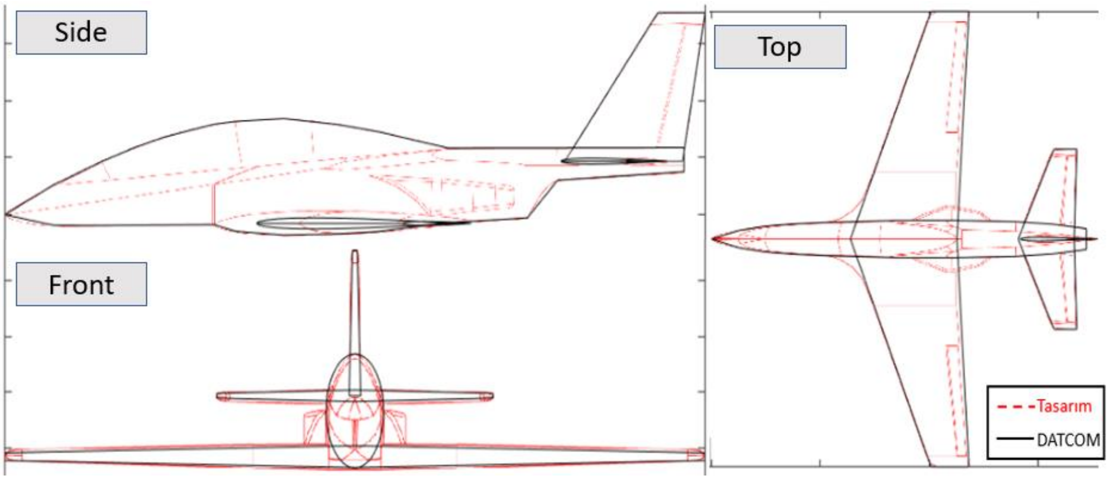

Figure 13: DATCOM and 3D Modeling Compare

According to this result, it was observed that there was only a small difference in the nose and wing tip of the aircraft defined in the DATCOM software, and it was verified and identified at a very reliable level. An example of the aerodynamic model pitching moment (C_m) created with the obtained aerodynamic data is shown in Figure 14.

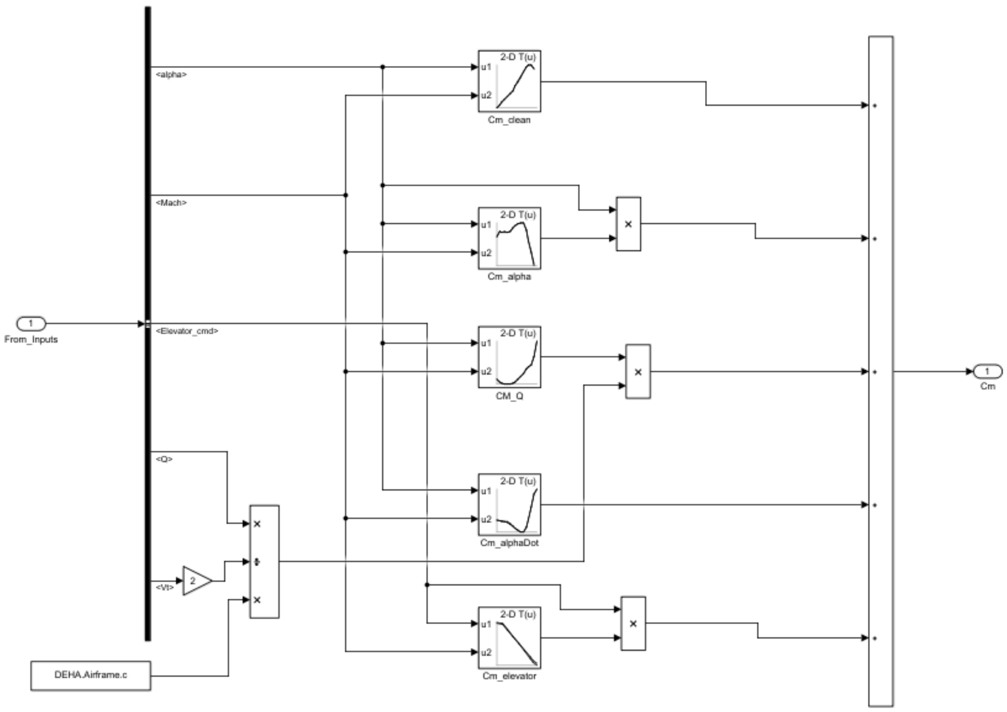

Figure 14: C_m Aerodynamic Model in Simulink

The model content of "AeroCoeffiecients_DATCOM" shown in Figure 15 is completed with the sub-model blocks and the conversion block to the body axis set for each aerodynamic coefficient.

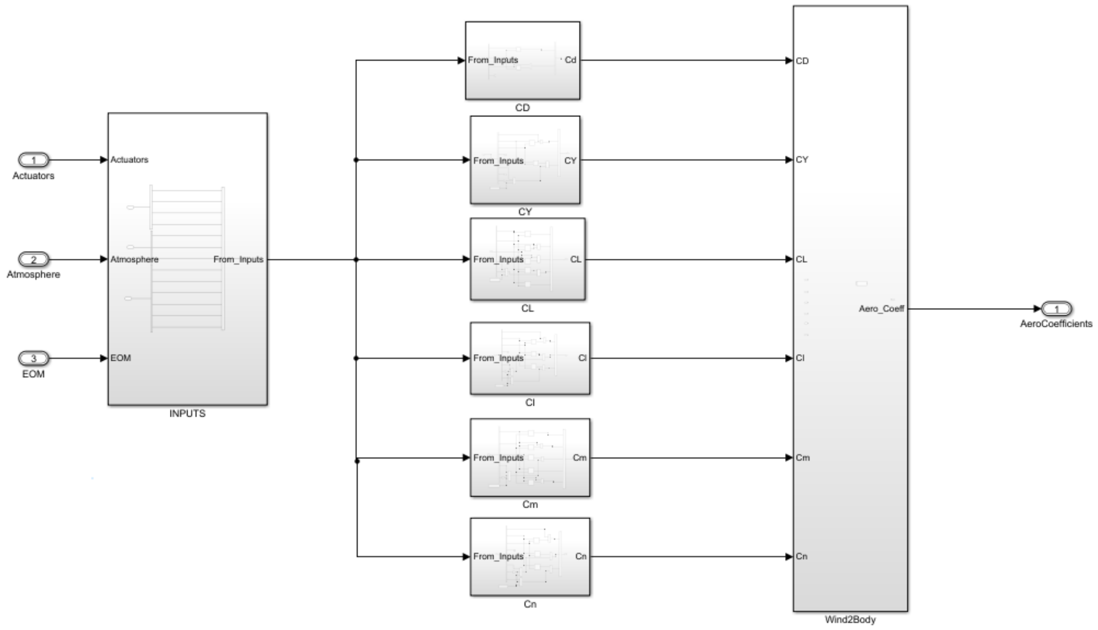

Figure 15: Aerodynamic Coefficients Model in Simulink

Some analyzes are carried out as a result of the models created from the aerodynamic database. The aerodynamic coefficients obtained and the lifting characteristics of the aircraft are shown in Figure 16.

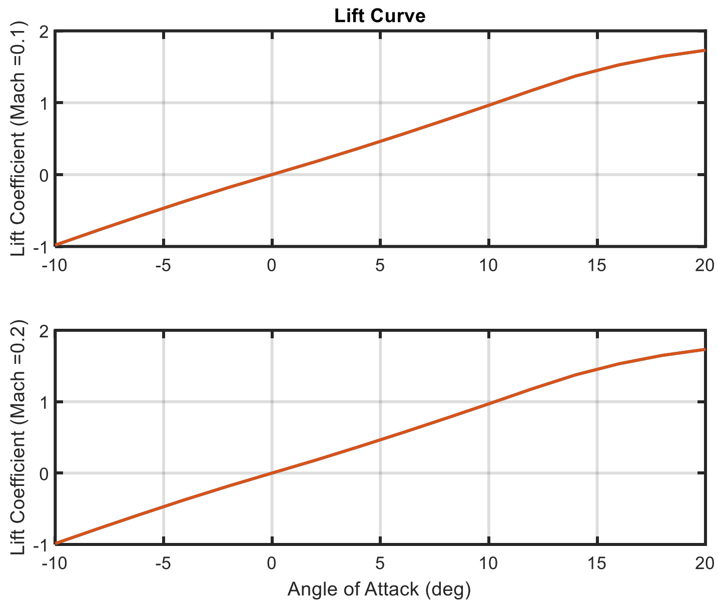

Figure 16: Aircraft Lifting Characteristics

The aerodynamic coefficients obtained and the drag polar characteristics of the aircraft are shown in Figure 17.

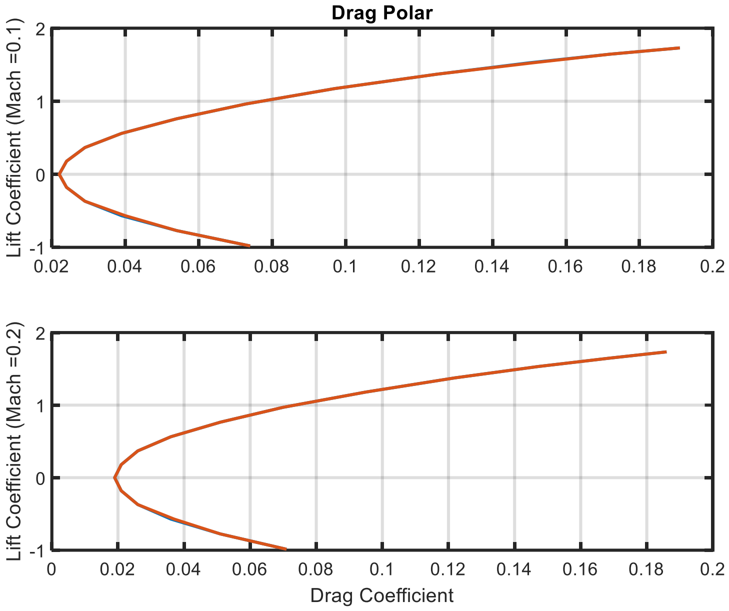

Figure 17: Aircraft Drag Polar Characteristics

In the modeling section, simulation modeling studies for the aircraft, its subsystems and atmosphere were carried out with the model-based design method.

CONCLUSION

This paper includes obtaining the simulation model of the experimental jet unmanned aerial vehicle (DEHA) by model-based design method, and the design and model validation. In this study, requirement, system architecture, design, implementation and verification, which are the stages of model-based design method, are handled in order. The studies started with requirements and system architecture, which are model-based systems engineering activities. In the requirements study, requirements were defined through the Simulink Requirements Editor, validated through the created checklist, traceability by the Simulink Requirements Perspective feature and verification of the requirements by the Simulink Test tool. In the system architecture study, the preliminary design of the simulation model that will reflect the aircraft dynamics was carried out with System Composer, a model-based design tool. Thanks to this system architecture, the behaviors, hierarchy, inputs and outputs of the sub-models in the aircraft simulation model have been determined. In the simulation model design studies, modeling of actuators, atmosphere, aircraft aerodynamics, jet engine used in aircraft, landing gear, aircraft mass, center of gravity and moments of inertia, forces and moments acting on the aircraft and equations of motion with 6 degrees of freedom were carried out.

In this study, a highly accurate simulation model was obtained for DEHA, a jet unmanned aerial vehicle, with a model-based design approach.

References

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