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Review of the doctoral thesis of Magdalena Peciak, MSc

"Application of Model Based System Engineering (MBSE) methods in designing hybrid and electric propulsion systems for aircraft"

supervised by:

Supervisor PhD, DSc, Eng. Wojciech Skarka, Prof. SUT

and Supervisor Prof. Dr.-Ing. Maik Gude, TU Dresden

1. Basis for the review:

Letter from the Chair of the Mechanical Engineering Discipline Council of the Faculty of Mechanical Engineering and Technology at the Silesian University of Technology, Dr Alicja Piasecka-Belkhayat, Prof. SUT, ref. no. RDIMe.512.70.2025.

2. Description of the content of the thesis:

The doctoral dissertation by Magdalena Peciak, MSc, entitled "Application of Model Based System Engineering (MBSE) methods in designing hybrid and electric propulsion systems for aircraft" is a coherent and interdisciplinary study devoted to the design of aircraft with alternative propulsion systems, including electric, hybrid and fuel cell-based systems. The author addresses a topic that is extremely relevant in the context of the aviation sector's transition towards low- and zero-emission solutions, pointing out that traditional design methods based on historical data for combustion engines are becoming obsolete in relation to new propulsion concepts. The thesis argues that the lack of historical databases can be replaced by parametric models linked to the four basic forces acting on an aircraft: lift, weight, drag and thrust.

The first chapter provides a broad introduction to the issue and emphasises the importance of reducing greenhouse gas emissions in aviation. The author presents the research objectives and scientific questions that determine the direction of further analysis. It is clearly

indicated that it is necessary to develop a new design methodology, based on a model approach, enabling the integration of alternative propulsion systems with the airframe already at the preliminary design stage.

In the second chapter, the author discusses the classic aircraft design process and points out its limitations with regard to alternative propulsion systems. The relationships between flight mission requirements and the main aerodynamic forces are described in detail, emphasising the importance of the T/W (thrust-to-weight ratio) and W/S (wing loading) parameters. This is followed by an overview of the available analytical and numerical methods used for hybrid and electric designs, pointing out both their advantages and limitations. This chapter serves to organise the material and prepare the ground for further research by the author.

The third chapter begins the original part of the dissertation. It classifies alternative propulsion subsystems into four groups: energy supply, energy conversion, thrust generation, and auxiliary systems. For each group, key design parameters are defined and models are proposed in the Matlab/Simulink environment using Simscape. The author shows how these parameters affect aerodynamic forces and how they can be used for iterative airframe design.

Chapter 4 presents models of entire propulsion systems: electric, hybrid and hydrogen-based fuel cells. Based on an energy-based modelling approach, energy flows between subsystems and their impact on flight mission characteristics were analysed. These models allow for the evaluation of the propulsion system's capabilities in various flight scenarios and are an example of the full integration of numerical calculations into the design process.

Chapter 5 focuses on the impact of alternative propulsion systems on the geometry and aerodynamic parameters of the airframe. Using OpenVSP software, parametric models of aircraft were developed to analyse different variants of energy source integration. It was shown that the location of batteries or hydrogen tanks significantly affects the shape of the fuselage, weight distribution and stability. This chapter introduces an important element of innovation by proposing iterative cooperation between the propulsion model and the airframe model.

Chapter 6 is application-oriented and constitutes a case study. The author presented a conceptual design of an aircraft with a PEM fuel cell-based propulsion system, starting with the requirements definition phase and then moving on to the selection of actual components and their integration into the airframe. This part of the work clearly confirms the usefulness of the proposed design methodology and is the culmination of the author's part.

Chapter seven contains the final conclusions. The author emphasises that the proposed model approach is an effective alternative to the lack of historical data and allows for the design

of new aircraft in a manner adapted to the realities of modern alternative propulsion systems. The conclusions are clear, logically structured and directly result from the research conducted.

In summary, the dissertation has a well-thought-out and logical structure. The author's part begins clearly with chapter three and is consistently developed in subsequent parts of the work, up to the case study in chapter six. The whole work is a valuable contribution to the development of the methodology of designing aircraft with alternative propulsion systems, based on reliable parametric models and the consistent integration of computational tools with the engineering process.

3. Originality of the work

Magdalena Peciak's thesis makes a significant and original contribution to aircraft design methodology by developing a methodology that replaces missing empirical data from historical models with data from parametric simulations directly related to the four main aerodynamic forces (L – lift, W – weight, D – drag, T – thrust). The originality of the approach lies in the consistent translation of Model-Based Systems Engineering (MBSE) assumptions into the process of designing alternative propulsion systems, whereby the author does not limit herself to analysing individual components, but builds a coherent system model covering both propulsion subsystems and airframe geometry.

The innovative elements of the dissertation can be identified in several dimensions:

1. Systematisation and parameterisation of propulsion subsystems. The author proposed a division into four functional groups: (i) energy supply (batteries, fuel tanks, hydrogen tanks), (ii) energy conversion (electric motors, fuel cells, generators), (iii) thrust generation (propellers, fans) and (iv) auxiliary systems. Each of the subsystems was described by a mathematical model in the Matlab/Simulink environment using Simscape libraries, which enabled their combination in a multi-domain approach. The classification defined in this way and its implementation have not yet been presented in the literature in such a complete and orderly form.

2. Integration of subsystem models in the drive system. An original contribution is the development of configurations for complete systems: all-electric, hybrid-electric and fuel cell. An energy-based modelling methodology has been introduced, which allows for the monitoring and balancing of energy flows throughout the entire system, including chemical-electrical conversion in fuel cells and energy accumulation in batteries. This approach enables the evaluation of system performance in real time

during a mission, which significantly expands the analysis capabilities compared to classical empirical models.

3. Linking propulsion models with the airframe model. The author introduced an original feedback procedure between the propulsion model and the aerodynamic model of the airframe developed in OpenVSP. It has been shown that the location of energy sources (batteries, hydrogen tanks) affects the geometry of the fuselage, mass distribution and stability parameters, thus forcing iterative modifications to the design. This is a valuable solution, as classical design methods treat the propulsion system and airframe separately, without mutual coupling.
4. Case study – aircraft with PEM fuel cells. The most complete manifestation of the originality of the dissertation is the conceptual design of a fuel cell-powered aircraft. The author carried out the process from the requirements phase, through the selection of commercially available components, to integration into the airframe model and simulation analysis. Such a comprehensive application study, making full use of the developed methodology, proves the practical usefulness of the proposed approach and confirms the originality of the work.

In summary, the originality of Magdalena Peciak's dissertation lies in the development and application of an integrated design methodology based on MBSE and parametric models, which combines the modelling of propulsion subsystems in the Simulink environment with the aerodynamic model of the airframe in OpenVSP, enabling iterative design optimisation. The work is innovative, as partial analyses dominate in the world literature, while the author presented a complete, systematic process of designing aircraft with alternative propulsion systems.

4. Practical value of the work

Magdalena Peciak's master's thesis has high utility value, which clearly places it in the area of research with real applications in engineering practice. The developed design methodology, based on parametric models and a systemic approach, allows for the replacement of missing historical data, which is particularly important in relation to electric, hybrid and hydrogen propulsion systems, for which there are no comprehensive and reliable empirical databases yet. The presented subsystem models in the Matlab/Simulink environment, extended with Simscape elements, enable the construction and analysis of complete propulsion system configurations in various variants and flight missions, which is a direct tool supporting the conceptual design process. A separate practical value is the integration of these models with the airframe model developed in OpenVSP, which allows the assessment of the impact of energy source locations

on the geometry, mass distribution and stability of the structure, thus supporting iterative design improvement. The energy-based modelling approach used is also of particular practical importance, as it allows the flow of energy throughout the system to be tracked and the efficiency of its individual components to be assessed, enabling potential energy limitations to be identified and the efficiency of the system to be increased. The case study of an aircraft powered by PEM fuel cells fully confirms the usefulness of the proposed methodology and can serve as a reference point for future research and implementation projects in the field of light and regional aviation. An additional value of the work is the possibility of adapting the developed models and procedures to other branches of transport where electric and hybrid systems are used, which significantly broadens the application potential of the dissertation. The whole work is not only theoretical, but also highly pragmatic, with a clear focus on practical applications in aeronautical engineering and related transport technology sectors.

5. Discussion points

Magdalena Peciak's MSc thesis is comprehensive and logical, and its value lies not only in the development of a coherent methodology, but also in opening up new research opportunities. In this perspective, it is worth pointing out several areas that may become a natural field for further scientific research and development of the presented solutions.

The subsystem models developed in Matlab/Simulink and Simscape fully achieve the conceptual objectives of the thesis. A debatable but interesting direction for further work is to gradually supplement them with data from laboratory measurements or component manufacturers' specifications. This would allow for further increases in the realism of the simulations and the introduction of experimental validation elements. The integration of propulsion models with the airframe in OpenVSP is an original and valuable element of the thesis. In the longer term, this stage could be developed by applying advanced aerodynamic analyses, such as CFD calculations, which could deepen the conclusions regarding the impact of energy source distribution on the flight characteristics of the structure. Such an extension would be a logical continuation of the adopted systemic approach. The case study of the PEM-powered aircraft clearly confirms the usefulness of the methodology. A debatable possibility for developing this part of the research is a variant analysis covering different types of airframes and mission scenarios. This would allow for an even more complete demonstration of the universality of the methodology and its potential for adaptation in different design contexts.

In summary, the points for discussion mainly concern the possibility of further developing and deepening the research. They do not refer to shortcomings in the work, but, in the reviewer's

opinion, indicate natural paths that may strengthen and broaden the scope of the developed methodology in the future.

6. Final conclusion

In conclusion, I believe that the work meets the requirements for doctoral theses set out in the Act on Higher Education and Science. Considering the fundamental nature of the research presented, I would classify it as belonging to the field of engineering and technical sciences in the discipline *of Mechanical Engineering (*Act on Higher Education and Science, Journal of Laws of 2018, item 1669). **Taking the above into account, I hereby submit a motion to admit the thesis of Magdalena Peciak, MSc, to public defence.**

In connection with the above, I present a positive conclusion and kindly request that the doctoral dissertation in question be accepted. I also request that **the Mechanical Engineering Discipline Council of the Faculty of Mechanical Engineering and Technology at the Silesian University of Technology** admit **Magdalena Peciak, MSc, Eng.,** to the next stages of the doctoral procedure. - Act of 20 July 2018 - Law on Higher Education and Science (Journal of Laws of 2021, item 478, as amended).

Dr hab. inż. Dariusz M. Perkowski, prof. PB

/podpis odręczny/

*wyłączenie jawności w zakresie danych osobowych oraz ochrony prywatności osoby fizycznej na podstawie art. 5 ust. 2 ustawy z dnia 6 września 2001 r. o dostępie do informacji publicznej (tj. Dz.U. z 2016 r., poz. 1764)

Małgorzata Jamka

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Białystok, 30 September 2025

Application for distinction of the doctoral thesis of Magdalena Peciak, MSc

"Application of Model Based System Engineering (MBSE) methods in designing hybrid and electric propulsion systems for aircraft"

supervised by:

Supervisor PhD, DSc, Eng. Wojciech Skarka, Prof. SUT

and Supervisor Prof. Dr.-Ing. Maik Gude, TU Dresden

Considering the high scientific level of the doctoral dissertation by Magdalena Peciak, MSc, its consistent and logical structure, the originality of the proposed methodology and its significant application value, I request that it **be awarded a distinction**. Particularly noteworthy is the innovative application of *Model-Based Systems Engineering* methods in the design of aircraft with alternative propulsion systems, the consistent integration of propulsion subsystem models with the airframe model, and the practical case study of a fuel cell-powered aircraft, which fully confirms the usefulness of the developed methodology. The dissertation is innovative in nature, and its results are in line with the current needs of the aviation sector's transition towards zero-emission propulsion systems. All these features justify awarding the dissertation a distinction.

Dr hab. inż. Dariusz M. Perkowski, prof. PB

/podpis odręczny/

*wyłączenie jawności w zakresie danych osobowych oraz ochrony prywatności osoby fizycznej na podstawie art. 5 ust. 2 ustawy z dnia 6 września 2001 r. o dostępie do informacji publicznej (tj. Dz.U. z 2016 r., poz. 1764)