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"Fuel Cell and Hydrogen Technologies in Aviation"

Edited by Can Ozgur Colpan (Dokuz Eylül University, Turkey) and Ankica Kovač (University of Zagreb, Croatia), Sustainable Aviation Series, Springer Nature Switzerland AG, 2022, 202 pages, ISBN: 978-3-030-99017-6, £109.99, €123.46, US$131.36

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NON-PEER REVIEWED FEATURE

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Introduction

"Fuel Cell and Hydrogen Technologies in Aviation" was written to explore critical cutting-edge technologies in the decarbonisation of the aviation industry. The tone of the book strikes a good balance between accessible and technical, and is targeted towards a range of audiences, from undergraduate students to interested individuals. The book begins with storage technologies, then covers hydrogen fuel cells, continues into logistics, life cycle analyses and finishes with alternative fuel cell technologies.

The editors, Can Ozgur Colpan and Ankica Kovač, are both academics in mechanical engineering departments, though each chapter has a different set of expert authors from a broad range of disciplines appropriate to the chapter. This is indicative of the breadth of topics that must be considered for realising hydrogen technologies in aviation. The book is written in good English and has a well thought out balance of diagrams and text. All diagrams in the book are clear and are related directly to the text.

Storage Technologies and Liquid Hydrogen as Fuel

The first two chapters consider various technologies for the storage and transport of hydrogen in aerial vehicles. Hydrogen has a long history in aviation and is still the standard for rocket propulsion. However, there are significantly different storage requirements for one-time rocket propulsion and for multi-use aircraft. Chapter 1, by Dirk Kastell (Hamburg, Germany), gives an overview of several technologies, from physical storage systems of gaseous and liquid hydrogen through to chemical and adsorption storage. Hydrogen melts at 13.99 K, boils at 20.33 K at 1 atm, and so is typically stored at 350 bar or 700 bar. The author of Chapter 1 provides several useful comparison tables and plots, including commentary on the relative benefits or challenges for each. Chapter 1 ends with a comprehensive comparison of hydrogen tank solutions in aircraft including several schematics and diagrams that help to put the various storage technologies in context (**Figure 1**).

Chapter 2, by Michael Bracha (H2 Coaching und Seminare, Germany), covers the history and state-of-the-art for the use of liquid hydrogen as aviation fuel. This chapter provides interesting insight into the evolution of liquid hydrogen storage technologies, from the first liquification of hydrogen by James Dewar in 1898 through to large-scale liquefier

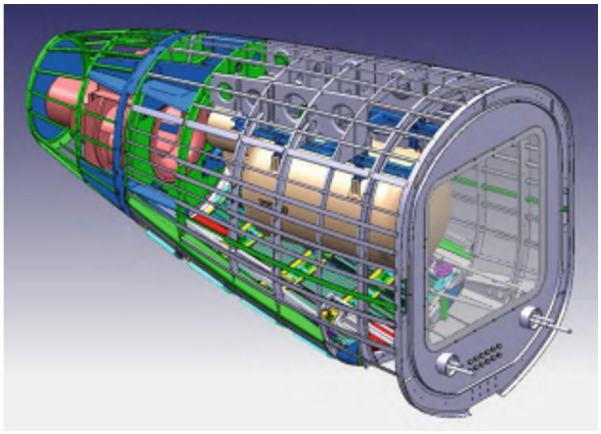


Fig. 1. Installation of one liquid hydrogen tank in the empennage of a mid-sized aircraft. Reprinted from (1), Copyright 2022, Springer Nature

plants currently being constructed in anticipation of increased demand over the coming years. This chapter also contains some useful infographics comparing hydrogen and kerosene, highlighting the decreased weight-load but increased volume load when using liquid hydrogen in place of kerosene. The chapter finishes with a detailed analysis of various technological milestones that would need to be reached for transitioning to liquid hydrogen fuel. This includes discussions on several concepts such as water electrolysers generating green hydrogen onsite at airports and includes safety and other infrastructure considerations for fuelling and storing liquid hydrogen.

Fuel Cell Applications

Chapter 3, by Bin Wang (Xi'an Jiaotong University, China) and Dan Zhao (University of Canterbury, New Zealand), considers the application and applicability of the three main fuel cell technologies: hydrogen, methanol and solid oxide, for unmanned aerial vehicle (UAV) systems. UAVs have become increasingly known in recent years for their military (large, long-range UAVs) and aerial photography (small, short-range UAVs), though there are a wide range of applications that are large markets but less well known, such as agriculture. With the drive towards miniaturisation and electrification of UAVs, various technologies are currently being investigated. For very small and short flight time UAVs, battery power is sufficient, but is limited to flight times of up to 40 min. As reasoned by the author, this paves the way for the use of fuel cell technologies for UAVs. The three fuel cell concepts are introduced in basic form, with the advantages and disadvantages of each approach listed without bias. The chapter then continues with a discussion of using hybrid fuel cell, battery and capacitor systems to power UAVs before finishing with a detailed discussion of system design for a range of potential applications.

Chapter 4, by Tine Tomažič (Pipistrel Vertical Solutions, Slovenia), starts with a discussion of the evolution of hydrogen as a fuel for aircraft, first as a buoyancy medium, then as combustible fuel and finally as the fuel in fuel cell systems. The chapter then continues into discussion of several fuelling and heat management systems, before finishing with safety considerations, though it does not contain any specific operating conditions such as temperature, humidity or power density.

Chapter 5, by Pedro Muñoz (Universidad Nacional de Catamarca, Argentina), Gabriel Correa (Universidad Nacional de Catamarca) and Enrico Cestino (Politecnico di Torino, Italy), is a detailed discussion of energy management strategies for fuel cell-powered aircraft. The calculations contained in this chapter consider several options for operation and load requirements and highlight the need for comprehensive mathematical modelling at the system level when attempting to realise the fuel cell electrified powertrain for aviation.

Logistics

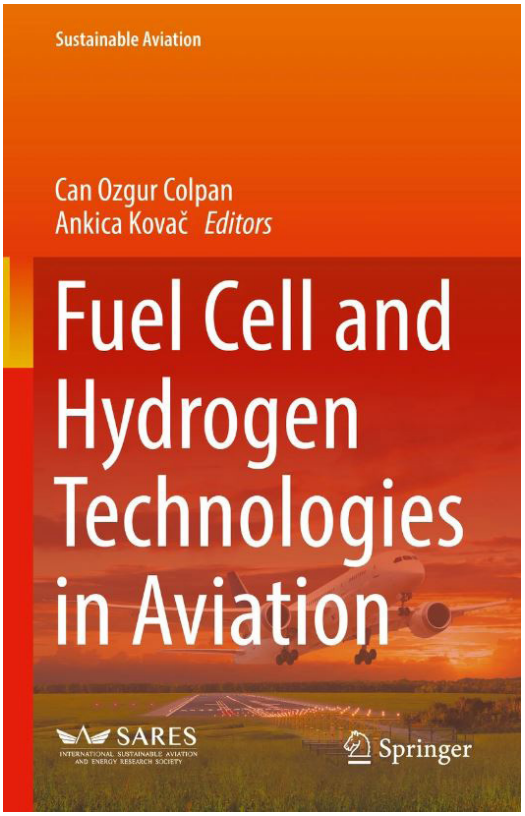
Chapter 6, by Maršenka Marksel, Rok Kamnik, Stanislav Božičnik and Anita Prapotnik Brdnik (University of Maribor, Slovenia), moves the discussion towards the logistical aspects of hydrogen infrastructure in airports. The detailed and honest discussion of the challenges and opportunities presented by hydrogen technologies is clearly laid out and carefully constructed.

Chapter 7, by Samuel Tadeu de Paula Andrade, Marina Domingues Fernandes, Victor N. Bistritzki, Rosana Zacarias Domingues and Tulio Matencio (Universidade Federal de Minas Gerais, Brazil), continues from the themes in Chapter 5, discussing the potential for using fuel cells as the auxiliary power unit (APU). The APU powers the electrical services of the aircraft and is typically linked to the main engine and fuel supply. This chapter discusses replacing the conventional APU with a fuel cell system, which will provide added benefits such as the generation of heat and water that can be used elsewhere on an aircraft. This chapter also contains an overview of the intellectual property space regarding fuel cell APUs, listing the majority of the major aerospace manufacturers.

The final chapter, by Vikrant Venkataraman (AVL List GmbH, Austria), focuses on solid oxide fuel cells. Several architectures are discussed and compared with proton exchange membrane fuel cells. The author of this chapter discounts the use of hydrogen as fuel, and rather considers the use of a solid oxide fuel cell system with a flexible approach to fuel type, including kerosene. This chapter does, however, have an interesting discussion on the power requirements of various sizes and shapes of aircraft during take-off, climb, cruise, ground operations and taxiing.

Conclusions

The mix of general introduction and applications-focused literature review helps to achieve the intended broad appeal of the book. This book could be used as an accessible introduction to the concepts of realising hydrogen technologies in aviation but could also be a handy reference for a more experienced researcher, with several practical hints and tips. The quality of the writing does vary from chapter to chapter, as one would expect from a research-focused textbook drawing on authors from both industry and academia. On the whole, however, this is a clear, concise and useful introduction to the breadth of considerations involved in applying hydrogen technologies in the aviation industry and would be a good addition to the bookshelf for anyone that is seeking to gain deeper understanding in some way.



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The Reviewer

Alex de Bruin joined Johnson Matthey in January 2017 after completing a PhD in colloid science and nanomaterials at the University of Bristol, UK. In 2021 he joined the Fuel Cells Research group as a Senior Formulation Scientist, where his research is focused on formulating fuel cell catalyst layers for heavy duty applications. Alex is also a Visiting Research Fellow at the School of Chemistry, University of Bristol.