HYDROGEN POWERED FUEL CELL PROULSION SYSTEMS FOR ELECTRIC AIRCRAFT

André Thess[1], Ricardo Kessel[1], Cornelie Bänsch[1], Christoph Gentner[1], David Diarra[1], Asif Ansar[1], Lukas Schnörer[1], Oliver Thalau[1], Josef Kallo[2], Felix Frey[2], Steffen Flade[2], Steffen Poggel[2], Sven Schmidt[2], Riaan Myburgh[3], Periklis Lolis[3], Jasmin Eberharter[3], Benno Petersen[4], Marc Häming[4], Julian Szasz[4]

1. Institute of Engineering Thermodynamics, German Aerospace Center (DLR), Pfaffenwaldring 38-40, 70569 Stuttgart, Germany
2. H2Fly, Augsburger Straße 293, 70327 Stuttgart, Germany
3. Deutsche Aircraft GmbH, Oberpfaffenhofen Airport, 82234 Wessling, Germany
4. Diehl Aerospace GmbH, Alte Nussdorfer Str. 23, 88662 Überlingen, Germany

Abstract

The quest for sustainable aviation has spurred research into innovative propulsion technologies, with a focus on reducing carbon emissions and achieving the goals outlined in Flightpath 2050. The Institute of Engineering Thermodynamics at the German Aerospace Center (DLR) and its collaborative partners have undertaken the development of hydrogen-powered fuel cell-based propulsion solutions for an electric aircraft. This paper delves into two notable projects, namely the 328H2-FC initiative and the BALIS test field, both aimed at enhancing hydrogen fuel cell and liquid hydrogen tank technologies for regional aircraft powertrains. These advancements mark significant strides towards realizing a decarbonized aviation industry.

1. INTRODUCTION

The escalating concerns over environmental impact have prompted a paradigm shift in aviation propulsion research. Hydrogen fuel cell technology presents a promising avenue for achieving sustainable air travel. This paper presents the efforts of DLR and its partners in pioneering hydrogen-powered solutions for electric aircraft, exemplified by the BALIS test field and 328H2-FC project. After testing of hydrogen powered fuel cell system in flying platforms and identifying application-specific challenges, a holistic approach of further development has been taken to develop zero-emission regional aircrafts through BALIS and 328H2-FC. One of the key challenges addressed by consortium is on determining the operating points of primary and auxiliary fuel cell systems for the prevailing environmental and different flight conditions during the mission. The detailed analysis was conducted to attain the dimensioning of the components to realize a critically reliable high-performance system with highest possible specific energy density. Together with industrial partners, hydrogen- and fuel cell-based propulsion concepts in the megawatt range are being conceptualized and analyzed by means of theoretical investigations. Furthermore, for experimental investigations, “BALIS” test field is currently being set up and put into operation. BALIS will enable to attain ground tests for system components and full integrated power system with liquid hydrogen in megawatt range. The measurement data recorded in the process will be used to validate DLR's own methods, but industrial partners can also access the test platform to develop and industrialize the latest generation of reliable and sustainable energy transition technologies. Moreover, 328H2-FC project is accomplished to improve the hydrogen fuel cell technology for the boundary condition of regional aviation powertrains and facing the challenge of decarbonizing aviation according to the goals of Flightpath 2050. A fuel cell system upscaled to 1.5 MW and fed by a tank system storing liquid hydrogen is under development for a 40 passenger regional aircraft. By side of the key technology blocks the electrical power distribution and a hydrogen energy controller need to be developed and also the limited available space for the integration of the systems need to be considered. Requirements for the systems in terms of safety and operability are based on CS-25 as the permit to fly is one goal. The process of developing a system in a new power class for this technology in aviation will show further steps to improve. Based on that DLR intends to further develop solution for 70 PAX regional aircrafts and supports the commercialize of this technology.

2. DEVELOPMENT METHODOLOGY

The development trajectory spans fundamental conceptualization (Fig 1), numerical analysis, component testing, integrated demonstrators, flight tests, and permit-to-fly. Flight testing of hydrogen-powered fuel cell systems in platforms has revealed application-specific challenges, spurring a comprehensive approach to further development. This holistic strategy encompasses conceptualization, design, engineering, testing, integration, and certification, with a focus on achieving zero-emission regional aircraft.

3. ADDRESSING DESIGN CHALLENGES

A pivotal challenge lies in determining design and optimal operating points for fuel cell systems under varying flight conditions. Different sizing and components configuration can be adapted to address the needs of mission as shown

 doi: 10.25967/610476

in Fig 2 and Table 1. Critical components, including stacks, air supply, cooling units, and electrical coupling, are tested individually relying on safety critical avionics computers enabling incremental integration and a high level of flexibility. Rigorous analysis guided the dimensioning of components to establish a reliable, high-performance system with maximal specific energy density.

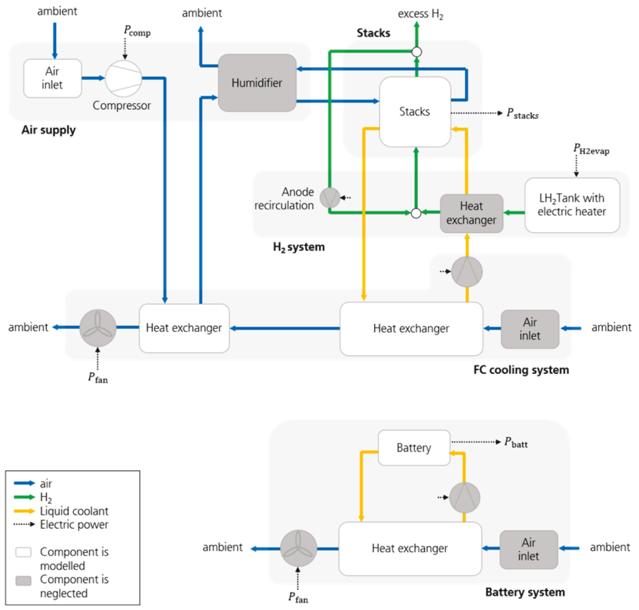

Fig 1: Generic system layout of airborne fuel cell and battery system

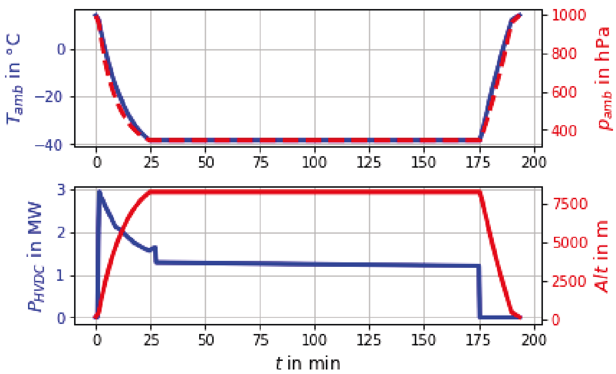

Fig 2: Mission profile with power demand and ambient conditions

Table 1: Different possible designs of fuel cell systems to meet the demands of missions

Type of system design	No. of stacks	System efficiency during cruise	Mass of heat exchanger for power at take-off	Mass of stack
High efficiency	49	40%	400 kg	2060 kg
Light weight	23	31%	810 kg	970 kg

4. TESTS IN FLYING PLATFORM

Prior to the development of large fuel cell propulsion system, fuel cell systems of sub-hundred-kW power were integrated and tested in flying platforms included Antares (33 kW, 1 PAX, range of 750 km, max speed 176 km/h) and HY4 (Fig 3.) (50 kW, 4 PAX, 1500 km, max speed 200 km/h). The mission profile (Fig 4 a) and resulting power management by powertrain (Fig 4 b) show that with suitable sizing and integration, all aspects of the mission can be successfully covered by fuel cell power train including take-off, climb, cruise, maneuver, approach and landing.

Fig 3: HY4 flying platform with 50 kW fuel cell propulsion system

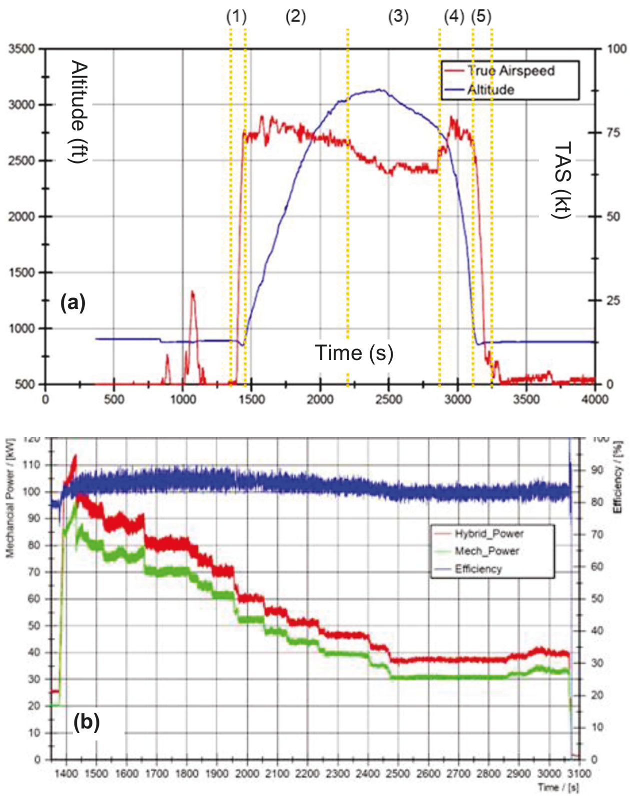

Fig 4: (a) Mission profile of a test campaign of HY4 flying platform with H2-FC propulsion system – (1) Take-off, (2) Climb, (3) Cruise, (4) Approach, (5) Landing and (b) The power need of motor (green) and power supply from fuel cell & battery system (red) showing secure follow-up and power management.

5. MEGAWATT-RANGE PROPULSION CONCEPTS AND BALIS

Collaborative efforts extend to conceptualizing and theoretically analyzing hydrogen- and fuel cell-based propulsion concepts in the megawatt range. This exploratory phase, with industrial partners, aims to lay the groundwork for experimental investigations. The "BALIS" test field (Fig 5), currently under construction, is to facilitate ground tests for system components and fully integrated power systems, employing gaseous but also liquid hydrogen in the megawatt range. Measurement data acquired will validate methodologies and guide the development of sustainable energy transition technologies. The testing capabilities of BALIS are given in Table 2. For BALIS, DLR procured advanced avionic components and MW-range from Diehl Aerospace. The latter were a customized development by Collins (HSG).

Fig 5: Picture of the modular BALIS test field covering a surface area of 2000 m².

Table 2: BALIS test field key components and their specifications.

Component type	Component power and specifications
Fuel Cells	Total Power of 1500 kWel Divided into two strings of 750 kWel Capable of testing units from 120 kWel
Electric Motors	Recuperating dynamometer up to 1800 kWel with initial setup of 2x 600 kWel 10 kNm, 30000 rpm Single shaft, Torque measuring shaft
Hydrogen tank unit	Useful mass of approx. 160 kg Pressure of 6 bars with max of 8 bars Mass flow of 120 kg/h
Evaporator	Power of 134,1 kW Outlet temperature min 5 °C Uses heat from fuel cells
Cooling unit	Approx. 3000 kW
Hydrogen storage	Useful mass of approx. 2500 kg Operation pressure up to 8 bars

6. THE 328H2-FC PROJECT

A notable endeavor within the research framework is the 328H2-FC project. This initiative seeks to enhance hydrogen fuel cell technology readiness for regional aviation powertrains. A powertrain of up to 1.5 MW, fueled by a liquid hydrogen storage system, is under development for the technology demonstrator based on an existing regional 328-100 aircraft (Fig 6) utilizing new IMA technologies for highly complex controls. Key challenges that are addressed include design and architecture of fuel cell system and electrical power distribution. Further work is on-going for enhanced specific power, hydrogen supply control, spatial constraints for system integration within the aircraft and improved thermal management system. Compliance with CS-25 safety and operability standards is imperative, reflecting aspirations for permit to fly authorization.

Fig 6: Rendering of the 328-100 based technology demonstrator with additional E-motors developed by GE

7. FUTURE PROSPECTS

The pioneering journey towards a novel powertrain based on hydrogen fuel cell technology in aviation is anticipated to yield invaluable insights. As the technology evolves and matures, further refinements and commercialization are expected. These developments will be key enabling technology to step up the efforts for first product development and commercialization by 2035 as well as to target development of larger regional aircrafts. These innovations birthed through the collaborative endeavors of DLR and its partners hold immense promise in reshaping the trajectory of regional aviation towards a sustainable and greener future.

8. CONCLUSION

The partnership between the Institute of Engineering Thermodynamics at DLR and its industrial collaborators fostering a paradigm shift of innovation in the pursuit of sustainable aviation. The BALIS test field and the 328H2-FC project exemplify a holistic approach to propelling hydrogen-powered fuel cell technology, ushering in an era of zero-emission regional aviation. These endeavors not only advance technological boundaries but also underscore the collective determination to realize Flightpath 2050's vision of a cleaner aviation industry.

9. ACKNOWLEGEMENT

BALIS test field received funding from the German Federal Ministry for Digital and Transport (BMVD) managed through NOW and PtJ. 328H2-FC project received funding from the German Ministry for Economic Affairs and Climate Action (BMWK) managed through German Aerospace Center Project Management Agency for Aviation Research.