Compressed hydrogen storage in contemporary fuel cell propulsion systems of small drones

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Abstract. Drones called also Unmanned Aerial Vehicles (UAV) are one of the most growing up aircraft production sectors. Contemporary manufactured small drones use mostly electric engines for their drive. Application of such propulsion system needs elaborating of efficient and as light as possible energy sources for electric engines. There are used at present essentially two methods of energy storing suitable for these purposes i.e. batteries and production of electric energy on-board with use of Fuel Cells (FC). The second method requiring the hydrogen fuel to be supplied to FC is still in experimental phase however, results of researches are very promising. The review of systems of compressed hydrogen storage and on-board production has been presented in article. There have been presented several examples of experimental and commercial hydrogen feeding systems and essential technical problems with hydrogen storing for the needs of small drones.

1. Introduction
Growing interest of drones called more “serious” Unmanned Aerial Vehicles (UAVs) results from their advantageous features in the area of military and civil applications. Big drones are in use by military to special tasks such as Intelligence, Surveyance or Reconnaissance (ISR) and strictly military operations including air attacks.
The drive of big UAVs is usually turboprop or turbojet engine. Small UAVs (multi-copters and fixed wings aircraft) are driven mostly by electric engines because of their low weight and easiness of control. Micro-jet and micro-turbo-prop engines are also used but generally by aircraft modellers only. The electric engine is more efficient and reliable than combustion one. Besides, electric propulsion of small and mini UAVs makes a possibility for reduction of sound trace, elimination of thermal signature deriving from hot exhaust gases [1].
Equipment required for electric energy supply make the whole system heavy, limiting the flight time. Hence, for several years many R&D centres have been leading intensive works in aim of extending the endurance of drones – particularly small ones. Researches are focused on elaboration of light, efficient batteries and application of modern fuel cells (FC) to achieve the long endurance UAVs.
The other way to increase the flight time is the use of combination of batteries and fuel cells or gasoline-electric drive in hybrid systems. The main issue at present, not counting fuel cells is storage of hydrogen as the “fuel”.
The review of methods of compressed hydrogen storing and on-board production of electricity on the base of examples of different constructions of UAVs’ manufacturers is presented below as well as the basic technical specifications of discussed drones. Examples are listed according to manufacturer’s names and produced drones’ names.
2. Systems of compressed hydrogen storage combined with FC technology

2.1. FlightWave Aerospace Systems Inc. – Jupiter-H2 VTOL UAV (Vertical Take-Off and Landing)
One of the examples of compression storage of hydrogen fuel is the Jupiter-H2 UAV manufactured by California-based FlightWave Aerospace Systems Inc. [2]. Jupiter-H2 is the patrol quadcopter built with use of narrow carbon fibre reinforced composite profiles minimizing structural weight (figure 1). Propulsion of this UAV consists of eight motors (double system) driving blades of ducted fans. Compressed hydrogen tank of capacity of three-litres enables up to two hours of continuous flight. The new fuel cell module AC64 650W (described further) elaborated by Intelligent Energy firm works on hydrogen and ambient air. The “exhaust” emission consists only of a small amount of clear water vapour and hence is pollution-free. The two hours of flight time varies with the payload (max. 1.25 kg). Reduction of overall weight of Juiter-H2 is possible thanks to absence of batteries, because the driving system can be fed directly from the fuel cells. The dimensions of this UAV are approximately 0.8 m x 0.6 m (height x width) together with optional equipment (sensors and cameras) mounted with use of universal mount system [5]. Refuelling of compressed hydrogen tank is very quick in comparison to the required time of battery charging.

![Figure 1. Hydrogen-Powered Jupiter-H2 UAV](image)

2.2. Sparkle Tech Ltd. (Hong Kong) - Eagle Plus VTOL
Sparkle Tech Ltd. is the company related to UAV manufacturing, which office is based in Hong Kong and production facilities located in China (Dong Guang City). The small UAV Eagle Plus –VTOL (figure 2) designed by Sparkle Tech is one of examples of new concept of VTOL vehicles. This UAV represents the connection fix wing construction with an idea of multi-rotor drone’s properties. In this way the VTOL possibilities are joined to the high efficiency flight of fixed wing arrangement. The core structure of that drone is composite reinforced with carbon fibre.

![Figure 2. Eagle Plus VTOL manufactured by Sparkle Tech:](image)

The Eagle Plus of 3.5 m wingspan is driven by 500 W electric main engine fed from hydrogen fuel cell. Max payload included fuel tank and equipment is 10 kg. Like most of the fuel cell drones it is fitted also with batteries (here - in dual system) providing maximum safety and endurance 5 hours at cruise speed 100 km/h. Power consumption at cruise speed of 86 km/h is about 330-600 W for the
case of 16.7 kg MTOW (Max Take-Off Weight). According to company information the capacious fuselage of Eagle Plus VTOL is designed for carrying Liquid Hydrogen Tank and batteries [9]. The specification of Eagle Plus UAV is presented in table 1.

| Parameter                                 | Data     |
|-------------------------------------------|----------|
| MTOW                                      | 21 kg    |
| Empty airframe (w/o battery, payload)     | 12.5 kg  |
| Wingspan                                  | 3500 mm  |
| Length                                    | 1990 mm  |
| Height                                    | 300 mm   |
| Wing area                                 | 70 dm²   |
| Max payload (included Tank & battery, equipment) | 10 kg |
| Engine (main)                             | 500 W (electric) |
| Battery (LiPo 12s 10000 mAh x 1,9L/500w H2-cell x1) | 8.5 kg |
| Take off / landing                        | VTOL     |
| Endurance                                 | 5 hours  |
| Cruise speed                              | 100 km/h |
| Max speed                                 | 115 km/h |
| Stall speed                               | 86 km/h  |
| Runway                                    | 5 m × 5 m |

2.3. MMC Micro Multi Copter Aero Technology Co. Ltd.
Chinese company MMC (headquarter located in Shenzhen) is the manufacturer of drones for industrial applications, among others agriculture, delivery, power line inspection, oil inspection, forestry fire fighting, mapping and public security surveillance. Present constructions of MMC’s drones driven with hydrogen fuel cells are presented below.

2.3.1. MMC’s HyDrone 1550. That UAV (figure 4) is the six propellers hydrogen powered drone whose lightweight carbon fibre air frame enables long flight time (up to 2.5 hours) and maximum payload 5 kg. Hydrogen fuel stored in a pressure bottle of 9 dm³ capacity fed the fuel cell stack (figure 5). Possibility of fast refuelling, rainproof and dustproof construction makes this UAV applicable in many environments independently on ambient temperature since hydrogen is a fuel not affected by low temperature. The specification of HyDrone 1550 is presented in table 2.

| Parameter | Data                                      |
|-----------|-------------------------------------------|
| MTOW      | 22 kg                                     |
| Maximum payload | 5 kg                                       |
| Width     | 1342 mm                                   |
| Length    | 1550 mm                                   |
| Height    | 610 mm                                    |
| Motors    | MMC 8108 (electric)                       |
| Propeller size | 736 mm                                    |
| Battery (spare) type / capacity / voltage | Li-Po 6s / 3000 mAh / 33.3–55 V |
| Hydrogen tank (CH₃) capacity | 9 dm³ |
2.3.2. MMC’s HyDrone 1800
The newest product of MMC company HyDrone 1800 is presented in figure 6 based on carbon-fibre frame as the HyDrone 1550. The construction is ‘almost indestructible’ according to the company and designed for use in the most difficult conditions. The HyDrone 1800 propulsion also uses the own elaborated by MMC’s technology of hydrogen fuel cells named H1. This solution is common for all MMC’s hydrogen driven UAVs. According to company’s statement HyDrone 1800 enables flight endurance up to 4 hours maintaining altitude 4500 m with payload of up to 5 kg. There is as well tethered version of HyDrone 1800 that achieves the continuous flight time about 50 hours.

2.3.3. MMC Skypatrol 2700 VTOL
Design of Skypatrol 2700 VTOL is functionally similar to Sparkle Tech’s Eagle Plus where construction based on combination of fixed wings and multi-copter properties enables to take off and land in places without landing strip. This UAV is equipped with Li-Po battery or H1 hydrogen fuel cell system depending on a version. General view of Skypatrol 2700 is presented in figure 7 and the basic data in table 3.

| Parameter               | Data          |
|-------------------------|---------------|
| MTOW                    | 22 kg         |
| Wingspan                | 3750 mm       |
| Length                  | 1890 mm       |
| Height                  | 300 mm        |
| Wing area               | 94 dm²        |
Max payload (included Tank & battery, equipment) 10 kg
Engines electric
Fuel (hydrogen) supply H1 fuel cell
Take off distance / landing VTOL
Endurance up to 7 h
Minimum speed 0 km/h
Max speed 110 km/h
Max flight altitude 5000 m
Runway about 5 m × 5 m

2.4. Intelligent Energy
The Intelligent Energy firm located in Loughborough (UK) operating among the others in Japan, Singapore, US and France specializes in fuel cells manufacturing. The present representative of Intelligent Energy’s fuel cells is AC64 650 W FC, forming the stack inbuilt in lightweight FC module. That air cooled system works on hydrogen and ambient air what is the common feature of almost all fuel cells being applied to small UAVs’ propulsion. Intelligent Energy’s FC systems for UAVs were presented first time in 2017 year [15] as the source of energy of a specially prepared to that purpose drone (figure 8). The AC64 650 W FC stack is shown in figure 9 and the general specifications are presented in table 4.

**Table 4. Specifications of AC64 650W fuel cell module for UAV [19].**

| Parameter                                          | Data                     |
|----------------------------------------------------|--------------------------|
| Maximum continuous power                           | 650 W                    |
| Maximum peak power                                 | 1000 W                   |
| Output voltage – custom configurable               | 14.8–25.2 V              |
| Energy capacity of 1.5 dm³ bottle (30 MPa)          | 600 Wh                   |
| Energy density of FC module (+1.5 dm³ bottle)      | 300 Wh/kg                |
| Dimensions of fuel cell module                     | 196×84×155 mm            |
| Dimensions of 1.5 dm³ H₂ bottle                    | Ø 116×238 mm             |
| H₂ bottle weight                                   | 1010 g                   |
| FC module weight                                   | 0.950 kg                 |
| Total FC module weight (+1.5 dm³ bottle)           | 1.960 kg                 |

**Table 5.** Approximated specification of UAV system with fuel cell module [19]

| Parameter                                          | Data                     |
|----------------------------------------------------|--------------------------|
| Maximum payload (for non-weight reduced platform)  | 0.50 kg                  |
60 minutes
5 to 35°C
3000 m
1000 hours

The AC64 650W FC module is equipped also with emergency battery of 1000 mAh capacity for safety of flight of UAV. The weight and dimensions (0.20 kg / 140×30×20 mm) correspond to the assumption of as low as possible mass of the whole UAV and provide emergency flight time about 2 minutes.

2.5. NRL’s Ion Tiger Fuel Cell Powered UAV

The U.S. Naval Research Laboratory (NRL) has been leading research works on their own designed PEM hydrogen fuel cell stack [20] presented in figure 10. Like most of other firm’s constructions that fuel cell stack uses oxygen from air.

![Figure 10](image)

**Figure 10.** US Naval Research Laboratory’s 550 W hydrogen FC stack [20].

The stack is made from titanium bipolar plates with use of 3D metal printing (sintering) which enclose commercial catalyst PEM membranes [19], [20]. The whole construction fastened by brass clamps is equipped with required auxiliary power-balancing equipment. Presented above fuel cell stack was first time applied to elaborated by Protonex 550 W hydrogen PEM FC module which was driven NRL’s Ion Tiger drone (figure 11) in 2009. That UAV made a 26 hours flight with about 2.3 kg of payload. Fuel cell module driving the Ion Tiger UAV is shown in figure 12.

![Figure 11](image)

**Figure 11.** NRL’s Ion Tiger fed with Protonex’s 550 W hydrogen PEM fuel cell [21], [22].

![Figure 12](image)

**Figure 12.** Protonex’s 550 W prototype of hydrogen PEM fuel cell module driving the Ion Tiger UAV (2009) [22].

| Parameter                        | Data                      |
|----------------------------------|---------------------------|
| Wingspan                         | 5.2 m                     |
| Length                           | 2.40 m                    |
| Height                           | ~ 0.5 m                   |
| Wing area                        | 1.57 m²                   |
| Payload (Tank & battery, equipment) | 2.5 kg                   |
| Engine                           | electric                  |
| Energy supply                    | Protonex 550 W - H₂ fuel cell |
| Hydrogen storage pressure        | 34.5 MPa                  |
| Endurance                        | 26 h                      |
2.6. Ballard Power Systems

Ballard Power Systems company which headquarter is located in Vancouver (Canada) developed in 2017 a new high performance fuel cell system provided for UAV’s propulsion [24]. Researches are led with help of Ballard’s subsidiary Protonex Technology Corporation located in Southborough (USA). Protonex is the manufacturer of advanced power management products and portable fuel cell solutions for military and commercial applications.

2.6.1 Scan Eagle UAV equipped with Ballard-Protonex FC Power Systems, Ballard-Protonex cooperates with Boeing-Insitu in aim of application of hydrogen FC power system to drive the Scan Eagle UAV. This power system is generally designed both for small unmanned fixed wing and VTOL UAVs. ScanEagle is one of the most “popular” and tested small UAVs in the world and is a good technology demonstrator platform also for hydrogen FC application. ScanEagle’s length is 1.55 m, wingspan 3.11 m, MTOW is 22 kg and reaches a ceiling of about 6000 m [25]. The ScanEagle operates as a part of system consisting of Mark4 Launcher – runway-independent catapult and SkyHook recovery system so a landing gear is unnecessary.

The contemporary Ballard-Protonex’s hydrogen fuel cell propulsion system for UAVs is presented in figure 14. The view does not included a compressed hydrogen bottle (or other H2 supply system).

2.6.2. Ballard’s FC with Non Precious Metal Catalyst, The very new construction of Ballard Power Systems made in collaboration with Nisshinbo Holdings (Japan) is the Non Precious Metal Catalyst (NPMC) for use in the PEM fuel cell. A high efficient catalyst layer was used in a prototype of 30-watt FCgen-1040 FC stack presented in 2017 [28]. This air-cooled FC stack is designed for application into ultra-lightweight UAVs or other constructions. The membrane electrode is built using a catalyst-coated membrane between two gas diffusion layers instead of the platinum metal.

Reduction of the amount of platinum in the fuel cell stack by more than 80 % in comparison to conventional PEM can result in potential cost savings of future FC production making this technology widely used. The prototype of FCgen-1040 micro fuel cell stack is presented in figure 15. The mentioned above catalyst is made from carbon alloy what is suitable for potential future low cost industrial production. Replacing platinum catalyst with a carbon alloy could significantly reduce the cost of fuel cells [29].
2.7. H3 Dynamics

H3 Dynamics company with headquarter located in Singapore consists of HES Energy Systems and HUS Unmanned Systems. The HUS branch elaborated two different concepts of unmanned aerial vehicles – a fixed-wing HYWINGS UAV (figure 16) and a long endurance multi-rotor HYCOPTER UAV (figure 19). Both vehicles are propelled by electric engines powered with HES’s own hydrogen fuel cell system which is 3 to 5 times lighter than Li-Po batteries.

2.7.1. HYWINGS hydrogen fuel cell UAV, HYWINGS is a fixed-wing unmanned aerial vehicle enabling take-off “from hand” without catapult. That UAV provides the possibility of quick hydrogen bottle refuelling (G-version) or quick exchange of hydrogen chemical cartridge (L-version) depending on a chosen variant. Specifications of HYWINGS UAV are presented in table 7.

![Figure 16. H3 Dynamics HYWINGS UAW propelled by energy from fuel cell [35].](image)

Table 7. Specifications of HYWINGS UAV [30], [31], [32], [33].

| Parameter               | Data                                                                 |
|-------------------------|----------------------------------------------------------------------|
| MTOW                    | 7 kg                                                                |
| Maximum speed           | 70 km/h                                                             |
| Cruise speed            | 50 km/h                                                             |
| Range                   | up to 500 km                                                        |
| Wind resistance         | 30 km/h                                                             |
| Energy supply (200 W)   | A-200 PEM – HES H₂ FC system, self-humidificated                   |
| Hydrogen storage        | • compressed, 30–35 MPa                                             |
|                         | • chemical, H₂ cartridge                                            |
| Engine                  | Electric                                                            |
| Endurance               | up to 10 h                                                          |

2.7.2. HES Energy Systems - Hydrogen Fuel Cell Power Supply System, Hydrogen FC power supply systems applied to H3 Dynamics’s drones are elaborated by H3 Dynamic division – HES Energy Systems. Construction of these systems depends on the type of chosen custom tailored system. Main differences are related to kind of hydrogen storage i.e. as compressed gas or chemical compound. HES manufactures hydrogen hybrid fuel-cell integrated systems named AEROPAK-G, AEROPAK-L and AEROPAK-S which are generally designed to drive fixed-wings UAVs of 5–50 kg mass. The HYWINGS drone is optionally fed with two systems – AEROPAK-G or AEROPAK-L. The AEROPAK-G system integrates ultra-light FC PEM of 200W electric power [32] and high pressure compressed hydrogen bottle (30–35 MPa) (figure 17).

![Figure 17. Elements of HES’s G-series hydrogen fuel cell power supply system: A-200 PEM fuel cell — left, G-series 300 bar composite bottle — right [31], [32].](image)

According to company’s statement G-series AEROPAK provides the HYWINGS flight time up to 6 hours. All propulsion systems contain small spare Li-Po battery to provide continuous delivery of energy in the case of peak energy demand or FC malfunction. HES designs at present small field refuelling systems for filling the H₂ storage bottles for HYWINGS and HYCOPTER UAVs. The AEROPAK-L uses a hydrogen-rich liquid chemical H₂ storage with combination of A-200 PEM fuel cell. The hydrogen on-demand chemical cartridge is one time use and enables quick “refuelling” by its
replacement. HYWINGS equipped with AEROPAK-L can fly up to 10 hours.

**Figure 18.** Elements of HES’s G-series hydrogen FC power supply system:
A-200 PEM fuel cell — left,
H₂ on-demand chemical cartridge — right [32], [33].

2.7.3. H3 Dynamics - HCYCOTER UAV, HUS Unmanned Systems produces a long endurance multi-rotor UAV – HCYCOTER1 designed for aerial inspection, surveillance, reconnaissance as well as search and rescue. HCYCOTER1 is the next generation of HCYCOTER which was a prototype with hydrogen storage in the special transparent cylinders being a part of UAV’s frame. The general view of both UAV’s generations is shown in figure 19.

**Figure 19.** Hycopeter prototype designed by HUS Unmanned Systems — left,
Hycopeter 1- the actual version — right [34].

The HCYCOTER1 is driven by ultra-light fuel cell stack fed from compressed H₂ bottle (30 MPa). Both FC stack and H₂ bottle with light weight pressure reducer are mounted within the UAV’s frame. The basic specifications of Hycopeter 1 are presented in table 8.

| Parameter       | Data                                    |
|-----------------|-----------------------------------------|
| MTOW            | 5.2 kg                                  |
| Energy supply system | A-200 PEM 200W – HES fuel cell        |
| Hydrogen storage | Compressed, 30 MPa                      |
| Engine          | Electric                                |
| Endurance       | 1.5–4 h flight (with 1kg payload)      |

3. Conclusions
Small UAVs (drones) have many advantageous features which make these "aircraft" very useful in different areas of commercial and military areas. There is however one drawback of them – not sufficient endurance. The energy for drones’ propulsion stored in batteries or FCs gives drones relatively short flight time after fuelling. Hence, many aviation related firms lead intensive researches in aim to elaborate the effective and light sources of energy for drones' propulsion. The miniaturization of FC stacks is one of possible development directions. One of most natural ways of energy storing is application of tanks of highly compressed hydrogen and their combination with efficient FC technology. These constructions are being the most intensively investigated at present although require light pressure bottles made from composites. The new idea of one-use energy systems presented in this paper occurred lately. This could be a good system for the smallest drones which mission is planned for a short time in repeating intervals. However one-use systems are the temporary solution until really efficient energy sources are developed. Taking under consideration present state-of-art in mentioned field it is difficult to foresee the close future of these propulsion systems. Maybe the development will go towards not described in this article interesting idea of the hydrogen fuel storage basing on chemical hydrogen compounds which easy release hydrogen on-board of UAV. One is sure, the future of civil and military transport largely belongs to drones both small and large.
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