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Airport hydrogen fuelling facility operations

Exploitation d'installation aéroportuaire d'avitaillement en hydrogène

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Contents

Page

Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/PAS 15594 was prepared by Technical Committee ISO/TC 197, *Hydrogen technologies*.

Introduction

When this document was introduced in the ISO/TC 197 programme of work, all aircraft- and airport-relevant procedures, systems and components concerning hydrogen technologies were in an early development state, and the technical solutions that would enable the future use of hydrogen as a fuel for aviation were not fully developed.

The development of this document within ISO/TC 197 depended on the progress achieved within the European Aeronautic Defence and Space Company (EADS)-Airbus Cryoplane project. However, this project is no longer planned to start in the near future, and there are no other relevant practical projects underway.

ISO/TC 197 experts are convinced that the subject of using liquid hydrogen in commercial aviation is of great importance and will gain new momentum in the next decade. As a result, the latest results are presented in this Publicly Available Specification to make the information available to all interested parties.

This document is not to be regarded as an International Standard. It records the latest results of ISO/TC 197 experts until the subject of using liquid hydrogen in commercial aviation gains interest.

It is understood that this document is far from complete and that it represents the knowledge available at the time of publication. Should work on this subject resume in the next years, the primary objective of the standardization work will be to ensure safety at all phases of handling while taking into account the conditions prevailing at civil airports and the results of risk assessment studies.

Airport hydrogen fuelling facility operations

1 Scope

This Publicly Available Specification specifies the fuelling procedures, hydrogen boil-off management procedures, storage requirements of hydrogen, and characteristics of the ground support equipment required to operate an airport hydrogen fuelling facility.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14687, *Hydrogen fuel — Product specification*

ISO 20421-1, *Cryogenic vessels — Large transportable vacuum insulated vessels — Part 1: Design, fabrication, inspection and testing*

ASME 1998, *Boiler and Pressure Vessel Code*

KSC[1)]-STD-Z-0009C, *Cryogenic Ground Support Equipment, Design of, Standard for*

KSC-STD-Z-0005B, *Pneumatic Ground Support Equipment, Design of, Standard for*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
block fuel
quantity of fuel to be used for refuelling prior to each flight

3.2
refuelling block time
time needed to refuel the aircraft, measured between connection and disconnection of the couplings

3.3
inert gas
nonflammable and nonreactive gas

EXAMPLES Helium, nitrogen, carbon dioxide.

1) Kennedy Space Center.

4 Symbols and abbreviated terms

AP	auxiliary power unit
CO	carbon monoxide
CO_2	carbon dioxide
C_nH_m	hydrocarbon containing n carbon atoms and m hydrogen atoms
EADS-Airbus	European Aeronautic Defence and Space Company
GH_2	gaseous hydrogen
LH_2	liquid hydrogen
N_2	nitrogen
O_2	oxygen

5 Fuelling procedures

5.1 General requirements

At the airport, the following situations shall be considered:

— normal refuelling during ground turnaround, with an onboard system in cold condition up to the refuelling/boil-off coupling;

— defuelling of the system on the ground due to planned maintenance activities and applicable troubleshooting cases;

— refuelling of a warm, air-floated onboard system before putting into service and after planned maintenance activities and applicable troubleshooting cases.

The airport infrastructure shall provide the ground support equipment required for performing the above-mentioned refuelling and defuelling operations, including the aircraft tank warm-up and precooling, the necessary purification and purging processes, and the evacuation and GH_2/LH_2 recovery that is required for defuelling operations and refuelling of a warm onboard system. Purge, precooling and warm-up procedures for the onboard fuel system shall be required only for putting into service, maintenance and troubleshooting activities.

The connection point between the aircraft and the ground support equipment shall consist of two couplings (similar but mistake-proof), a refuelling coupling for providing the tanks with LH_2, and a boil-off coupling for the discharge of GH_2. In Annex A, Figure A.1 provides an example of an aircraft refuelling and defuelling interface point and Figure A.2 an example of a hydrogen aircraft-fuel system layout.

5.2 Bonding and grounding procedures

Airport personnel shall apply appropriate bonding and grounding procedures prior to performing any refuelling or defuelling operations on an aircraft.

5.3 Refuelling of a cold system

For normal refuelling during ground turnaround, the airport personnel shall ensure that the tanks are cold and still contain a small quantity of fuel. The time required for the refuelling of a cold system shall be minimized and shall be such that the aircraft-refuel block time requirements can be met (see Annex B). The time required for the refuelling of a cold system shall include an acceptable time for connection and disconnection, including time for cleaning of inner cavities from air at connection and from hydrogen at disconnection, and time for warming before disconnection.

In order to perform the refuelling of a cold system, airport personnel shall use the following refuelling procedure.

a) Establish the connection of the refuelling and boil-off couplings between the aircraft and ground support equipment. Purging and precooling of the refuelling connecting hose and coupling need not be performed.

b) After the refuelling system is in “ready” mode, open the tank refuelling and boil-off valves to start the refuelling operation.

c) Monitor the fuel level of the tanks and control it using the refuelling and boil-off valves.

d) After filling the tanks, close the refuelling and boil-off valves and separate the couplings and auxiliary connections.

NOTE 1 The renunciation of purge, purification, evacuation and precooling at the coupling can be justified by existing advanced coupling designs.

NOTE 2 During the refuelling of a cold system, no boil-off gas is expected due to recondensation within the onboard tank.

5.4 Defuelling

For yearly maintenance checks or any troubleshooting, airport personnel may need to defuel the aircraft tanks. Defuelling of the aircraft fuel system shall be done using the refuelling and boil-off couplings.

After coupling the aircraft with the refuelling and boil-off connectors of the ground support equipment, an overpressure pipe on the gas side within the onboard tank should deplete the tanks back to the airport stationary storage tank or portable tank container. The onboard pumps could assist the depletion.

If warming up and purging of the aircraft tanks and piping are required, they shall be done using temperature-conditioned inert gases.

5.5 Refuelling of a warm system

Refuelling of a warm, air-floated onboard system shall be carried out before putting an aircraft into service and after planned maintenance activities and applicable troubleshooting cases. Perform the refuelling of a warm system as follows.

a) Purge the tank and piping system with an inert gas (evacuated, if possible) to remove the air or other foreign gases from the system. Decrease the foreign gas concentration within the system to an acceptable level that is yet to be determined, and measure at the boil-off coupling.

b) Purge the tank and piping system and precool with conditioned hydrogen to remove the inert gas from the system. Decrease the inert gas concentration within the system to an acceptable level that is yet to be determined, and measure at the boil-off coupling.

NOTE At the time of the publication of this PAS, no detailed procedure for refuelling a warm onboard fuel system could be given, because the initial state of the system before purge could differ and was not really known. The same applied to the required end-state of the system after purge and precooling. The requested procedure may vary due to the design of the onboard tank and piping system. The development task is to define a procedure which is optimized with respect to cost, time required, careful material handling, and safety aspects.

5.6 Monitoring of fuelling parameters

5.6.1 Monitoring during refuelling of a cold system

Control and monitoring during the refuelling of a cold system shall be implemented at one master logic point. A refuelling and monitoring panel shall provide the necessary monitoring indication and enable the selection of all possible automatic/manual procedures, including the preselection of the fuel quantity from the information provided by the aircraft automatic fuel-level control. Shut-off valves in connection with level indication shall execute the refuelling procedure. To avoid tank overfilling, the airport personnel shall monitor onboard-tank liquid level, pressure, temperature and valve positions.

The recommended position for the refuelling control and monitoring-panel is near the refuelling and boil-off couplings integrated in the aircraft structure. The possibility of monitoring the procedure from the aircraft cockpit and ground supply equipment should also be considered.

5.6.2 Monitoring during defuelling and refuelling of a warm system

Airport personnel shall perform control and monitoring during defuelling and refuelling of a warm system. Control and monitoring provisions shall be available from the airport ground infrastructure.

5.7 Monitoring of the safety parameters

5.7.1 General requirements for monitoring devices

Monitoring of the safety parameters is aimed at decreasing the risk associated with handling flammable and cryogenic fuel. Monitoring devices shall not interfere with the refuelling operations, and they shall not be an ignition source.

As much as possible, monitoring devices should be independent of external power supplies, and instead have their own internal power supplies. Devices that take their energy from the fuel (its pressure, flow, or low temperature) or are an integral part of the fuelling system should be given preference.

When a faulty condition is detected, monitoring devices shall trigger an interruption of the fuel flow if the line is already open, or the locking of the main valve if the line is still closed. An audible and/or visible alarm shall be activated indicating the kind of failure and where it occurred.

5.7.2 Monitoring of interface leakage

Interface leakage shall be monitored during the fuelling and defuelling operations. Interface-leakage monitoring shall enable the detection of

— leaks from the lines or the connections,

— open or not fully or faulty closed connections,

— other abnormal conditions that might be dangerous.

The tightness of the connection shall be verified by measuring the pressure decrease or increase in a suitably selected volume or by measuring the pressure difference between such a volume and atmosphere.[2)]

When a leak is detected, personnel shall verify the suspected area with foaming agents, leak detectors or equivalent methods.

2) Measuring pressure decrease or volume increase for tightness of a connection is not very responsive. However, no alternative technology was available at the time of the publication of this PAS. By the time any serious construction of large fuelling facilities for aircraft materializes, the field of hydrogen detection/situational awareness systems should be more mature and could be the preferred method of control and monitoring.

5.7.3 Overpressure

A mechanical contact manometer or an equivalent device shall be used to monitor overpressure in the onboard fuel system and shall be used to stop the fuelling operation immediately when an overpressure condition is detected.

5.7.4 Heat insulation deterioration

Airport personnel shall monitor signs of deterioration of the vacuum insulation. Suitable criteria shall be established to determine the amount of insulation deterioration that is acceptable, and that which requires repair or replacement. Deterioration of insulation can easily be detected in an early stage by observing the outer surface of the vacuum space becoming cold, and water condensing or even freezing on it.

A spot on which such effects can be detected shall be in the view of the airport personnel responsible for the refuelling operations. Means to detect temperatures that are too low can also be used.

In the open air or in a hangar, the air humidity is high enough for water vapour to undergo condensation. In areas where air humidity is too low, means other than visual inspection should be used to detect signs of deterioration of the vacuum insulation.

NOTE A metal rod that contracts when it cools and breaks a contact when its length falls under a certain threshold can be used to monitor deterioration of the insulation.

6 Hydrogen boil-off management

Airports that service hydrogen aircraft shall be equipped with boil-off gas user systems. These systems shall be designed to collect hydrogen boil-off gas generated in the onboard LH_2 tank (see Annex C for a description of the boil-off gas problem) during the following aircraft modes:

a) ground overnight parking (approximately 12 h);

b) long-time overhaul with cold tanks;

c) applicable failure cases.

The connection point between the aircraft and ground support equipment shall be the boil-off coupling, which allows a gas feed to the airport boil-off gas user system for utilization.

7 Storage of hydrogen

7.1 Storage capacity

The storage capacity for LH_2 shall be established based on the demand for hydrogen at the airport. LH_2 requirements for airports range from a few tons per day to 6 000 000 kg per day for a large airport.

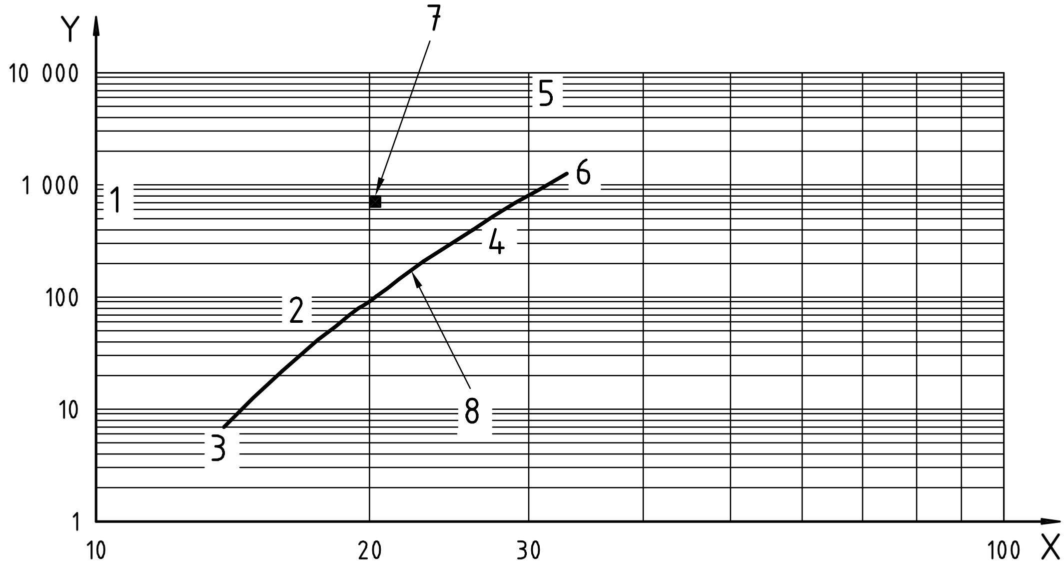
7.2 Storage means

LH_2 shall be stored at the airport either in portable tank containers or in stationary storage tanks. Considerations for the selection of storage means are provided in Annex D.

7.3 Properties of hydrogen stored at the airport

7.3.1 LH_2 state condition at aircraft refuelling interface point

LH_2 at the aircraft refuelling interface point shall have a pressure equal to or higher than 700 kPa and a temperature equal to or less than 20 K, as shown in Figure 1. The reasons that lead to the selection of the refuelling pressure and temperature requirements are provided in Annex E.



Key

X fuel temperature, kelvin
Y fuel pressure, kPa
1 solid
2 liquid
3 triple point
4 vapour
5 fluid
6 critical point
7 required fuel condition at aircraft interface
8 hydrogen equilibrium state

Figure 1 — Hydrogen refuelling condition

7.3.2 Hydrogen quality

LH_2 at the aircraft interface shall meet the requirements set forth in ISO 14687 for type II hydrogen fuel, with the exceptions stated below:

— LH_2 purity ⩾ 99,999 9 % (volume fraction);

— O_2 content ⩽ 0,000 02 % (volume fraction);

— N_2 content ⩽ 0,000 02 % (volume fraction);

— H_2O content ⩽ 0,000 05 % (volume fraction);

— C_nH_m content ⩽ 0,000 01 % (volume fraction);

— CO content ⩽ 0,000 01 % (volume fraction);

— CO_2 content ⩽ 0,000 01 % (volume fraction);

— LH_2 shall not contain particles > 5 µm.

The hydrogen shall not contain impurities in the form of particles large enough to cause component or aircraft fuel system malfunction. The maximum size of 5 µm given above needs to be confirmed, and the requirement specified in 8.7 adjusted accordingly.

In order to define the requirement for hydrogen purity, studies of impurities accumulation in aircraft tanks are needed. These studies should be carried out on tanks with near-real structural dimensions. At the time of publication of this PAS, there was no stable opinion about quantities and composition of dangerous impurities (oxygen, nitrogen, their mixtures).

NOTE It is a design aim for future serial aircraft to keep the onboard fuel system in cold condition for approximately 1,5 years. During this period, hundreds of refuellings will be carried out on a single aircraft, and O_2 and N_2 could accumulate within the aircraft storage system, jeopardizing the safety of the aircraft. In order to prevent such solid nitrogen and oxygen accumulation within the onboard fuel system, a high level of refuelled hydrogen purity and a control device within the aircraft storage system is foreseen. If procedures are developed and are proven efficient in avoiding this accumulation, either at the airport or on the aircraft, the hydrogen purity requirement could be decreased accordingly.

8 Ground support equipment

8.1 General requirements

Ground support equipment shall meet the requirements set forth in KSC-STD-Z-0009C and KSC-STD-Z-0005B and the additional requirements described in the following subclauses. If discrepancies are found between the requirements of KSC-STD-Z-0009C and KSC-STD-Z-0005B and the requirements set forth in the following subclauses, the most recent requirements shall prevail.

8.2 Stationary storage tanks

The storage tank shall consist of a suitably supported inner liquid vessel, enclosed within an outer shell with insulation between the inner liquid vessel and outer shell. The inner liquid vessel shall be made of appropriate stainless steel, and designed and constructed in accordance with, and fulfilling the requirements of, the ASME *Boiler and Pressure Vessel Code* in all respects. The outer shell of the tank shall be made of carbon steel with good weld-ability. Piping between inner and outer shells shall be made of appropriate stainless steel. Appropriate instrumentation for measuring temperature, pressure and fluid level shall be provided.

The boil-off rate of the storage tank shall be designed to match the proposed withdrawal rate of product from the tank, in order to minimize product losses. The annular space between the inner liquid vessel and the outer shell shall be evacuated and include an adequate insulating material. The insulating material shall not be subject to damage by hydrogen, in either its gaseous or liquid state. The insulating material shall not attack the material of the inner liquid vessel or the outer shell. The insulation shall be designed with a vapour-tight seal in the outer covering to prevent the condensation of air and subsequent oxygen enrichment within the insulation. The insulating material and outer shell shall be of adequate design to prevent insulation attrition under normal operating conditions. Means to monitor the vacuum level of the annular space between the inner liquid vessel and the outer shell shall be provided.

8.3 Portable tank containers

Portable tank containers shall be designed and constructed in accordance with and fulfill the requirements of ISO 20421-1 in all respects.

8.4 User system for boil-off gas

Different types of boil-off gas user systems can be used at the airports. Annex F gives an overview of the systems that can be implemented.

8.5 LH_2 pipelines

The inner pipeline shall be made of austenitic stainless steel, Invar or other material, provided it is proven to be equivalent in performance. Axial stresses due to thermal contraction of the inner line shall be analysed. Spacers between inner and outer pipelines shall ensure resistance to axial stresses. Pipeline configuration shall ensure that mechanical stresses are minimized. The choice of material for the outer pipeline will depend on the length of the pipeline.

The annular space between the inner and outer pipelines shall be evacuated and shall include an adequate insulating material. The insulating material shall not be subject to damage by hydrogen, in either its gaseous or liquid state. The insulating material shall not attack the material of the inner or the outer lines. The insulation shall be designed with a vapour-tight seal in the outer covering to prevent the condensation of air and subsequent oxygen enrichment within the insulation. The insulating material and the outer pipeline shall be of adequate design to prevent insulation attrition under normal operating conditions. Means to monitor the vacuum level of the annular space between the inner and outer pipelines shall be provided.

8.6 Refuelling and boil-off coupling units

8.6.1 Classification of refuelling and boil-off coupling units

Refuelling and boil-off coupling units shall be classified according to the following types, depending on the application:

a) Type I: Manual coupling units used for the refuelling and boil-off management operations of small aircraft;

b) Type II: Mechanized coupling units used for the refuelling and boil-off management operations of large aircraft.

8.6.2 Refuelling coupling units

Type I refuelling coupling units shall consist of a refuelling hose, a refuelling connector, and safety monitoring devices. The mass of the refuelling connector together with the attached part of the refuelling hose shall not exceed 10 kg (preferably 7 kg).

Type II refuelling coupling units shall consist of a refuelling hose, a refuelling connector, an actuator to provide reliable multiple pressurized sealings, and safety monitoring devices. The mass of the type II refuelling coupling unit is not limited.

NOTE Type I refuelling coupling units need not be equipped with an actuator. The actuator required to provide a reliable multiple pressurized sealing is expected to be installed on the aircraft.

8.6.3 Boil-off coupling units

Type II boil-off coupling units can be integrated in the type II refuelling coupling units.

8.6.4 Refuelling connectors

The refuelling connector of the type I refuelling coupling unit shall be designed and constructed to meet the requirements of the connectors used on road vehicles. The connector shall have a diameter of 30 mm.

The refuelling connector of the type II refuelling coupling unit shall be designed and constructed to meet the requirements of the connectors used on sea ships and liquid hydrogen carriers. The connector shall have a diameter of 140 mm.

NOTE At the time of the publication of this PAS, the requirements applicable to refuelling connectors for both type I and type II refuelling coupling units had yet to be established. Further work is required to define these requirements, including the diameter of the refuelling connectors.

8.6.5 Safety monitoring devices

Safety monitoring devices shall meet the requirements set forth in 5.7.

8.6.6 Refuelling points

The number of refuelling points has a direct effect on the supply method and the flow rates. More information is needed before being able to outline requirements on that subject.

The quantity of LH_2 to be refuelled prior to each flight ranges from 410 kg for a small aircraft, 6 700 kg for a medium aircraft, and up to 33 000 kg for a large aircraft (see Annex B).

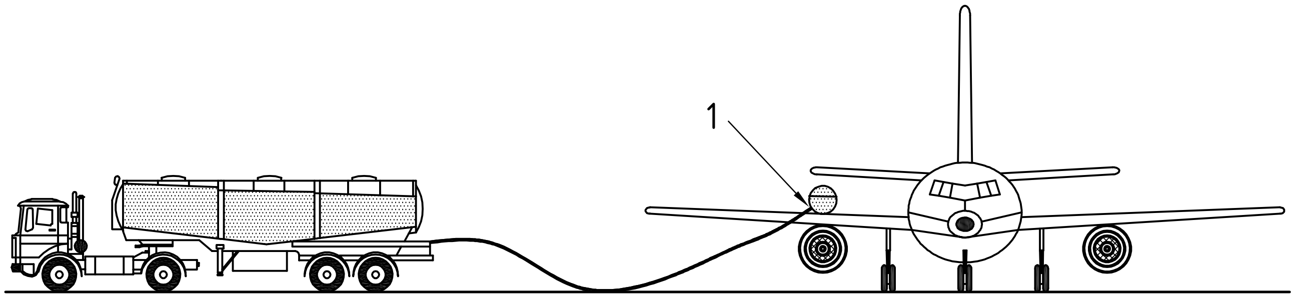
8.7 Filter on airport side

A mechanical filter, compatible with LH_2 cyclic transfer temperature and pressure shall be provided at or near the refuelling connector. The filter shall be suitable for removing 5 μm and larger-sized particles. Provisions shall be made to isolate, purge and remove the filter for cleaning. The purge provisions shall be suitable for identifying the cause of the blockage by delta pressure increase.

Annex A
(informative)

Example of a hydrogen aircraft fuel system layout and aircraft refuel/defuel interface point

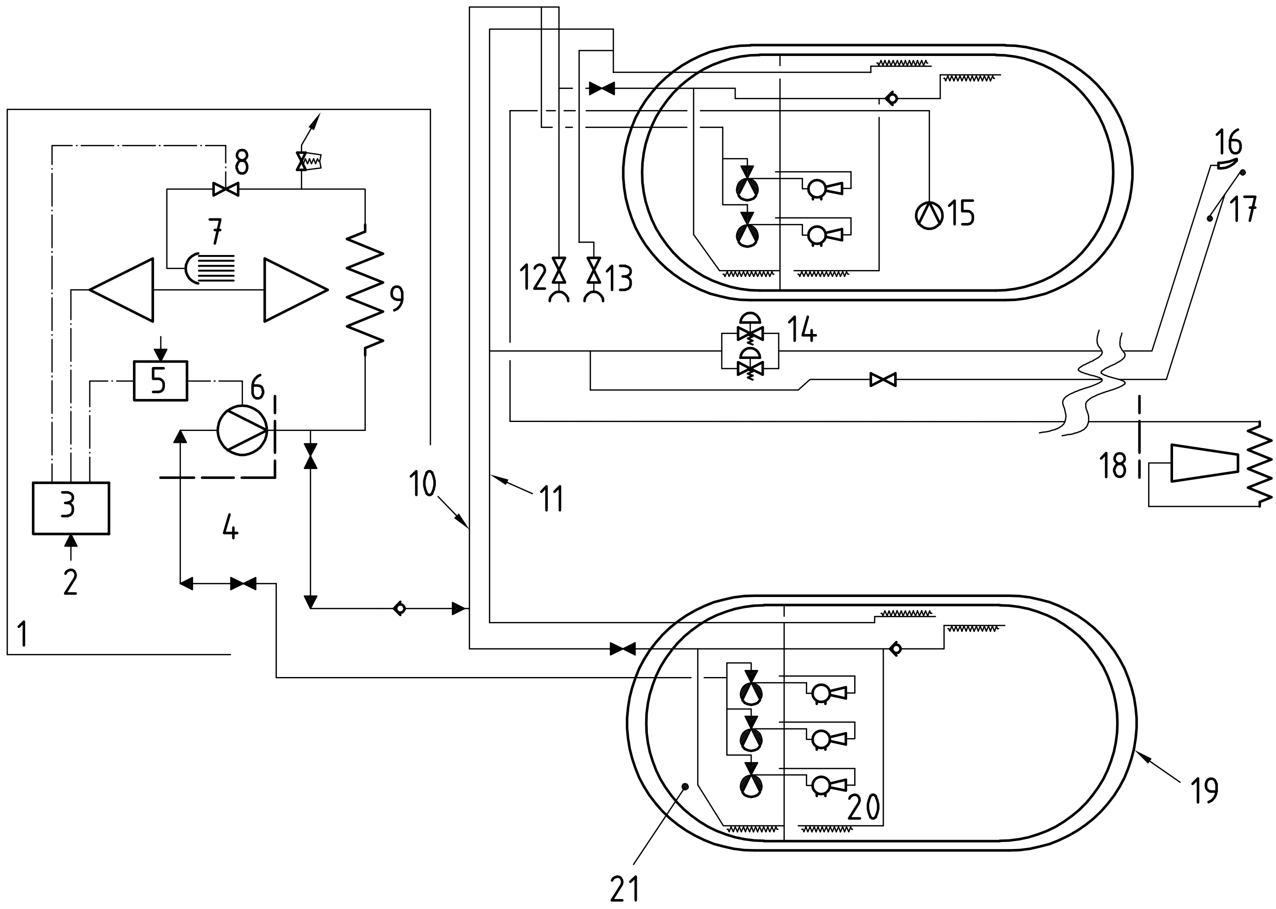
Figures A.1 and A.2 show examples of refuelling and of layout of a hydrogen fuelling system.



Key

1 aircraft refuel/defuel interface point

Figure A.1 — Example of refuelling the EADS-Airbus DO 328 LH_2 demonstrator with a mobile refuelling truck



Key

1 engine periphery (prel.)
2 from engine throttle
3 control & regulation unit
4 interface to engine
5 pump drive
6 HP-pump
7 combustion chamber
8 injection valve
9 heat exchanger
10 crossfeed line
11 gas drainage line
12 refuelling coupling
13 boil-off coupling
14 safety valves
15 HD-pump
16 exit for safety valves
17 exits for normal boil-off
18 interface to APU
19 heat insulation
20 jet pumps
21 tank pumps

Figure A.2 — Example of a hydrogen aircraft fuel system layout, LH_2 DO 328 demonstrator

Annex B
(informative)

LH_2 requirements for different types of aircraft

Type	Total fuel kg	Reserve fuel kg	Block fuel kg	Refuelling block time min	Estimated flow time min	Number of refuelling points	Tank operating pressure range kPa	Tank filling level %
Regional aircraft DO 328 LH_2 fan version Demonstrator 900 km mission One engine + APU modified	560	150	410	20	15	1	120 to 350	95
Regional aircraft DO 328 LH_2 fan version Serial aircraft type 900 km mission Two engines + APU modified	950	290	660	10	5	1 To be confirmed (TBC)	120 to 350	95
Medium-range aircraft A 321 LH_2 version Serial a/c type 4 000 km mission Two engines + APU modified	8 650	1 880	6 770	13	7	To be determined (TBD)	120 to 200	>95
Long-range aircraft A 340 LH_2 version Serial a/c type 9 300 km mission Four engines + APU modified	37 150	4 500	32 650	40	35	TBD	120 to 200	>95
Medium-range aircraft TU 334 LH_2 version Demonstrator 1 000 km mission One engine + APU modified	1 100	300	800	20	15	TBD	120 to 200	>95

Annex C
(informative)

Hydrogen boil-off in onboard LH_2 tanks

Hydrogen for use in aviation will be stored onboard at cryogenic conditions as a boiling liquid. Thus, the temperature of the hydrogen will be about 20 K. To avoid excessive production of GH_2, with associated tank pressure increase due to the inevitable heat flux into the tanks, a high quality of insulation will be necessary. Other heat leaks should be minimized as well.

The tank insulation-quality requirements are very different for the following applicable aircraft operational modes:

a) flight operation times;

b) normal ground service turnaround times;

c) other ground times:

   1) ground overnight parking (approximately 12 h);

   2) long-time overhaul with cold tanks;

   3) applicable failure cases.

Therefore, a compromise in tank insulation quality should be found to satisfy all of these operating modes, which leads to some unavoidable hydrogen boil-off gas in the onboard LH_2 tank. If it would be possible to consume this gas during all operational modes, the insulation quality of the tanks could be lowered considerably.

During flight operation and normal ground-service turnaround times, possibilities to reduce tank pressures could be found on the aircraft, for example:

— APUs or main engines are running and could be fed by gaseous hydrogen;

— the refuelling procedure could offer the possibility to reduce tank pressures by means of reliquefaction;

— the tank pressure could be allowed to increase to the upper limit, which is defined by the pressure differential at maximum flight altitude.

For the remaining ground cases, technical assistance is required from the airport infrastructure.

Annex D
(informative)

Considerations for the selection of storage means

Hydrogen can be produced locally or produced much farther away (outside production). In the case of local production, hydrogen could be stored in stationary storage tanks with a capacity of 270 000 kg of LH_2. However, this approach is costly from an infrastructure point of view, and it is probable that capacity will be built in incremental steps. For instance, hydrogen production units of 100 000 kg/day could be the minimum production amount but would not ensure a high degree of flexibility in meeting exactly the demand for hydrogen at the airport. High cost and less flexibility means that this storage approach will probably be complemented by another more flexible source of hydrogen, which could be met by an outside supply of hydrogen brought into the airport area by portable tank containers (3 000-kg or 6 000-kg capacity). Such tank containers could be transported by ship, truck, or railway.

Transfer of LH_2 from the portable tank container to a stationary storage tank could mean important energy losses. In addition, this transfer would not avoid the high infrastructure cost at the airport of the stationary storage tanks. Direct refuelling of the aircraft from portable tank containers should be implemented.

Portable tank containers could be trucked or put on a railway carrier. These methods would be appropriate in the following scenarios:

a) start-up phases of hydrogen-powered planes and airports when a hydrogen plant is not yet justified;

b) small airport to be supplied;

c) volumes of LH_2 required do not justify additional hydrogen plants at the airport;

d) cheaper hydrogen supply available from outside;

e) avoidance of costly storage infrastructure at the airport;

f) safety considerations concerning a large number of storage tanks close to the airport.

Annex E
(informative)

Selection of LH_2 refuelling pressure and temperature

The requirements for the refuelling pressure and temperature of LH_2 were established based on the following considerations.

a) The pressure has to be relatively high to achieve acceptable refuelling times on the order of 20 min with a small refuelling pipe diameter within the aircraft (to reduce mass and heat input).

b) A temperature as low as possible should be selected, to keep the pressure low within the aircraft tank at the end of the refuelling procedure and also to increase the refuel mass at a given tank volume (due to the density characteristics of LH_2).

Annex F
(informative)

User systems for boil-off gas

Table F.1 gives an overview of the user systems for boil-off gas that could be implemented at airports. Each applicable system can be achieved in different kinds of installations (for example: mobile ground vehicle, stationary installation).

The advantages and disadvantages of the different systems are multifarious, even for the different phases of hydrogen introduction into aviation applications (short-/mid-/long-term view) and are not discussed here.

Table F.1 — Types of user system for boil-off gas

System	Mode	Possible application
Direct use of GH_2 energy	Chemical combustion by fuel cells Thermal combustion by reciprocating engines H_2/O_2 steam generator	Electrification of ground vehicles
Storage of GH_2	Storage of gas within pressure vessel	Diverse applications
GH_2 reliquefaction	Joule-Thompson process Magneto-calorific process	Refuelling aircraft
GH_2 discharge to ambient[3)]		

The following parameters should be taken into consideration for the selection of potential systems for the gas user:

— safety-related points;

— compatibility with existing aircraft and airport systems;

— investment and operating costs for airport and airlines;

— reliability, availability, and development risk of the proposed systems.

Each airport has different operational and boundary conditions that require different solutions for the problem of user systems for gas. Handling of the aircraft boil-off gas may vary from airport to airport.

Preliminary investigations lead to the recommendation of a mobile fuel system as the first choice during the introductory phase of hydrogen-fuelled aircraft. For later phases, stationary fuel systems seem attractive.

3) Discharge of GH_2 to ambient is an attractive solution from the technical point of view; however, with regard to safety and economy, it is not desirable.

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[8] EN 12300, *Cryogenic vessels — Cleanliness for cryogenic service*

[9] EN 12312-5, *Aircraft ground support equipment — Specific requirements — Part 5: Aircraft refuellers, hydrant dispensers and fuelling equipment*

[10] EADS-Airbus Document, *DO 328 LH2 Demonstrator: Fuel system;* 1996

[11] EG- Safety Data TRGS 220

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[16] NFPA 50A, *Standard for Gaseous Hydrogen Systems at Consumer Sites*

[17] NFPA 50B, *Standard for Liquefied Hydrogen Systems at Consumer Sites*

[18] NSS 1740.16, *Safety Standard for Hydrogen and Hydrogen Systems*

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