(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
31 January 2019 (31.01.2019)

WIPO | PCT

(10) International Publication Number
WO 2019/021234 A1

(51) International Patent Classification:
F02K 9/42 (2006.01) *F02K 99/00* (2009.01) *F03H 99/00* (2009.01) *F02K 9/62* (2006.01)

(21) International Application Number:
PCT/IB2018/055595

(22) International Filing Date:
26 July 2018 (26.07.2018)

(25) Filing Language: Italian

(26) Publication Language: English

(30) Priority Data:
102017000087235 28 July 2017 (28.07.2017) IT

(72) Inventor; and
(71) Applicant: **MINOTTI, Angelo** [IT/IT]; VIA LAURI 32, 00037 SEGNI (RM) (IT).

(74) Agent: **LEONE, Mario** et al.; c/o Cantaluppi & Partners S.r.l., Viale della Tecnica 205, 00144 Roma (IT).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,

(54) Title: SPACE PROPULSION SYSTEM

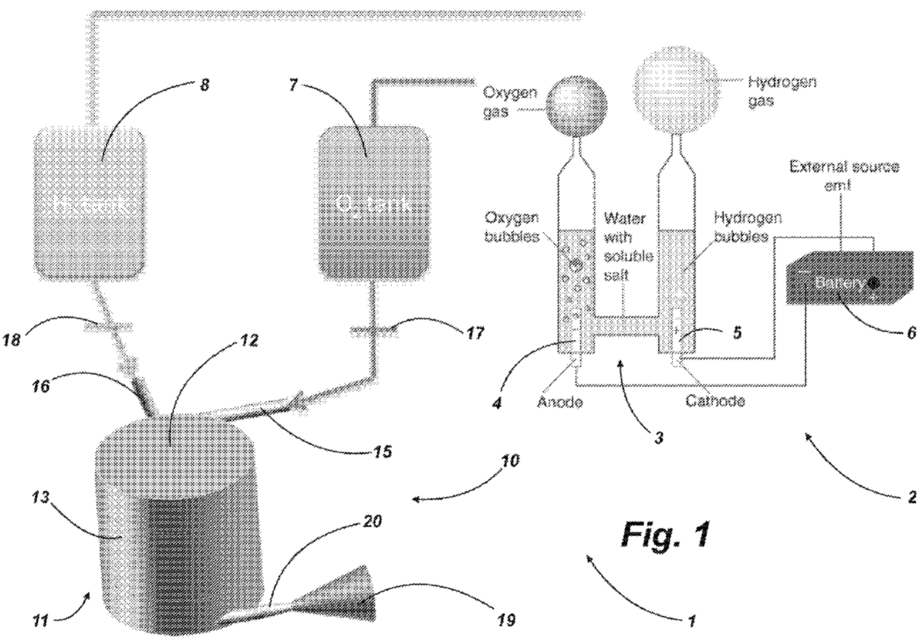

Fig. 1

(57) Abstract: A space propulsion system (1), having reduced sizes, is designed specifically for the application on miniaturised satellites, but it can be scaled easily based upon a wide range of sizes of the target vehicle, and it comprises: a combustion chamber (10) implemented by a cylindrical container (11) having cylindrical walls (13), a first end (12) provided with at least an injection duct (15) for a combustion agent, a fuel and/or a mixture thereof, for the injection according to a direction tangential to said cylindrical walls so as to induce a helical combustion path in the combustion chamber (10), a possible additional perpendicular injection duct (16) for a fuel or a combustion agent, and an opposite end (14) provided with a discharge duct (19) arranged according to a direction tangential to said cylindrical walls (13) so as to receive and direct said helical path, wherein the cylindrical walls in case have a deposition of catalytic material inside thereof, for accelerating the combustion reaction; and a supersonic nozzle (20), connected to said discharge duct (19)

WO 2019/021234 A1

[Continued on next page]

TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*
— *with amended claims (Art. 19(1))*
— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

for discharging the combustion products in the combustion chamber.

Space propulsion system

The present invention relates to a space propulsion system, of the type particularly suitable for a range of small size space satellites, in the specific case miniaturised artificial satellites known under the terms "microsatellite" (10 ÷ 100 kg), "nanosatellites" (1 ÷ 10 kg) and "picosatellites" (100 g ÷ 1 kg) which can be orbited by low payload launchers, and which can require a propulsion system both with the purpose of correcting their position and performing orbital changes and prolonging the residence time in low orbit.

An example of satellite whereon this propulsion system could be used is constituted by the satellites of *CubeSat* class, typified by California Polytechnic State University (Cal Poly) and Stanford University, the provided size thereof is that of a cube having 10-cm side, and a weight comprised between 1.0 kg and 1.5 kg, which can be used alone or in cluster (constellation) in a "low" earth orbit, that is with a maximum altitude of 700 km but even lower than 160 km, which usually produces a quick orbit decay due to the interference with the earth atmosphere.

It is important to underline that, nowadays, the nano-pico satellites travel along the release orbit of the main payload, usually a macro-satellite, and they are provided substantially with systems for the positioning and not with propulsion systems so as to allow optimum collocations. This is due to the reduced sizes of the nano-satellites which make difficult to create an effective propulsion system with very small sizes.

It is meant however that the present invention is not to be considered limited to the use in combination of satellites and space probes having reduced sizes, but it can even be used as auxiliary or emergency propulsion for space vehicles having any size, MMU (*Manned Maneuvering Unit*) devices used for extravehicular activities of astronauts and so on.

Examples of propulsion systems suitable to the above-mentioned purpose are known. The US patent N. 5,932,940 A describes a propulsion system for the altimeter check of satellites or for space objects such as probes and the like, which comprises rotating members such as a gas microturbine provided with a compressor.

The presence of rotating portions and the use of gaseous fuels, although they can satisfy some needs in the field of miniaturised satellites, make complex the satellite structure and tend to increase the overall weight thereof, without a real gain in autonomy corresponds thereto.

Other thrust systems provide the use of inert gases pressurized at the liquid state, but they have a limited autonomy and low performances.

Even electrical systems have been proposed wherein the acceleration of particles, in case particles with electric charge, is obtained for example thanks to the Hall effect. These systems require reduced quantities of propulsion fluid and they do not need moving portions, but usually produce thrusts having very low extent.

As contrary features, chemically-based propulsion systems are known, wherein the required energy is obtained by means of a combustion reaction between a fuel and an oxidizing agent. In this case the thrusts which can be obtained have no limit, but it is necessary to include in the vehicle payload even determined amounts of fuel and combustion agent with the related confinement systems.

Moreover, for obvious reasons, the need is particularly felt to have a propulsion system with as much energy effectiveness as possible, but which could produce thrusts of a certain extent, if compared to the sizes of the satellite thereon it would be used.

Zeledon, R. A. "Electrolysis Propulsion for Small-Scale Spacecraft, Cornell University, Dissertation in partial fulfilment of the Requirements for the Degree of Doctor of Philosophy, May 2015 - analyses the potentialities of a water propulsion system, with separation electrolytic system, but it uses a low-effective combustion chamber with an electrical (spark) combustion ignition system.

Other examples of propulsion systems which exploit the water electrolysis as fuel and oxygen source are described in the US patents N. US 3,490,235 A; N. US 4,345,729 A and N. 3,517,508 A.

The technical problem underlying the present invention is to provide a propulsion system allowing to obviate the drawback mentioned with reference to the known art.

Such problem is solved by a propulsion system as defined in the enclosed claim 1; additional details of the invention are defined in the enclosed depending claims.

The idea underlying the present invention consists in integrating different technologies therebetween with a combustion chamber with helical inner motion, in case provided with a catalytic deposition on the inner cylindrical surface thereof for accelerating the combustion reaction, and with a nozzle at the discharge of such combustion chamber for creating a thrust.

It is to be meant that this scheme can be used with any combination of fuel and combustion agent, which can be injected separately in the combustion chamber or together in a mixture, suitable to react in the combustion chamber.

In order to manage the payload the combustion agent could be pure oxygen, provided under the form of compressed gas or molecules which can be divided by electrolysis, for example under the form of water.

In a preferred example of the invention, it can comprise a water tank and an electrolytic system, for the division of water into hydrogen and oxygen which then will be recombined in the above-mentioned combustion chamber.

The electrolytic system, operating with gravity or with recirculation pump, can be separated from the tank or integrated therein, thus capable of providing a gaseous mixture of hydrogen and oxygen which can be injected directly in the combustion chamber.

It is further meant that even other compounds could be used as fuel, for example hydrocarbons. A preferred version provides the use of compressed methane.

A propulsion system results therefrom, having reduced sizes, designed specifically for application on miniaturized satellites but which can be easily scaled based upon a wide range of sizes of the target vehicle.

This propulsion system the can make independent the miniaturised satellites, which then could perform autonomous orbit changes, extend their operating life, create constellation of satellites cooperating therebetween; they could extend mission targets of lunar probes and/or deep space; they could vary their position along the orbit depending upon contingent needs; they could operate in low altitude to obtain a better resolution and so on.

The present invention will be described hereinafter according to some preferred embodiment examples, provided by way of example and not for limitative purposes with reference to the enclosed drawings wherein:

* figure 1 illustrates the functional scheme of a first embodiment example of a space propulsion system according to the invention;
* figure 2 shows a perspective view of a component, a combustion chamber, of the propulsion system of figure 1;
* figure 3 shows a plan view of the combustion chamber of figure 2;
* figure 4 shows an additional perspective view of the combustion chamber of figure 2; and
* figure 5 illustrates the functional scheme of a second embodiment example of a space propulsion system according to the invention 1 to 4.

By referring to the figures, a space propulsion system is designated as a whole with 1. It comprises an electrolytic system 2 for dividing liquid water, transported in a container 3 split up into two branches, intended for gaseous hydrogen and oxygen, respectively.

The container 3 of the electrolytic system can constitute the only water tank available to the propulsion system, and this solution is suitable to satellites with minimum sizes, whereas for other larger-sized solutions and payload an additional tank feeding the container 3 can be provided.

The electrolytic system 2 then comprises an anode 4 and a cathode 5, arranged near or inside a respective branch of the container 3, which are subjected to an electric voltage produced by a battery 6, which, in turn, can be charged by a photovoltaic system existing aboard the space vehicle.

It is to be meant that the battery 6 is just a possible example of electric energy among the ones which can be used.

The gaseous oxygen and hydrogen bubble in the respective branches of the tank 3 at the anode 4 and the cathode 5 respectively. Then, they feed a respective tank of oxygen 7 and a respective tank of hydrogen 8 having reduced sizes, since the preservation of the propulsion fluid is implemented under the form of water in the liquid state, wherein hydrogen and oxygen occupy a minimum space without requiring a complex confinement system.

As it is known, the water should at least be slightly dissociated in ions to allow the passage of electric current. To this purpose, it will include an adequate quantity of electrolyte, for example an acid or a dissolved salt.

The above-mentioned tanks are not strictly necessary but they can be useful should a higher gas injection than the productive capability of the electrolytic system be required, or for having flows characterized by higher pressures than those produced by the simple electrolytic process, or at last to obtain an immediate reaction by the propulsion system 1.

It further comprises a combustion chamber 10, which burns gaseous hydrogen and oxygen, with a helical inner motion so as to increase the residence time of the reagents and of the products so as to allow high combustion efficiencies in very small volumes.

The combustion chamber 10 comprises a cylindrical container 11 developing along a longitudinal axis having a first flat end 12 thereat there are two injection ducts therethrough oxygen and hydrogen are injected. The combustion chamber 10 further has cylindrical walls 13 extending from said first end 12 to a second end 14 wherein the discharge nozzle is positioned.

In particular, a first injection duct 15 is provided which is tangential to the cylindrical walls of the chamber 10 and which is arranged parallel to the plane of the first end 12. The position of the first injection duct 15 is so that it imposes a helical motion to the flow of oxygen and hydrogen which react therebetween.

Furthermore, a second injection duct 16 is provided which is perpendicular to the cylindrical walls of the chamber 10 and it is arranged parallel to the plane of the first end 12. The position of the second injection duct 16 is so that the inlet in the chamber 10 takes place near the inlet of the first duct 15, so that the gaseous flow injected through the first duct 15 intersects the gaseous flow injected through the second duct 16.

In the present example, the first injection duct 15 is fed by gaseous oxygen, whereas the second duct 16 is fed by gaseous hydrogen.

Considering that the available oxygen and hydrogen derive from the water electrolysis, they are provided with the exact required stoichiometric ratio. However, the interposition of tanks 7, 8 could require the presence of respective valves of oxygen 17 and hydrogen 18.

It is to be known that the flow of gaseous oxygen has a rate of flow by weight eight times higher than the rate of flow by weight of the gaseous hydrogen, due to the molar ratio between the two water components.

Therefore, the first injection duct 15 imposes to the gaseous flow resulting from the mixing of the two gases a helical path, with a helix which unwinds for the whole extension of the combustion chamber 10 as far as its second discharge end 14, by lengthening considerably the path of the combustion reaction and then even the related residence time of the reactant gases.

The cylindrical walls 13 of the cylindrical container 12 can show on their inner surface a deposition of catalytic material which produces an acceleration of the combustion reaction between oxygen and hydrogen. Preferably, the catalytic material mainly comprises Platinum.

Thanks to the catalytic material, the temperature for triggering the hydrogen oxidation reaction is lowered. In a preferred version of the device, such lowering, together with the lengthening of the combustion path, allows the ignition of the combustion reaction with development of flame without no outer ignition intervention is required.

Alternatively, the device can be provided with means for flashing an ignition spark in the combustion chamber 10.

In each case, it is meant that the combustion chamber is implemented in one single piece, and it has only the openings necessary to the injection and to the discharge.

Therefore, this combustion chamber exploits the fluid dynamics and the chemistry (catalysis) to increase to the maximum the residence time of the combustion and to reduce to the minimum the time of chemical kinetics. These solutions allow to simplify the construction of the combustion chamber by reducing, at the same time, the sizes thereof.

According to a variant, the combustion chamber 10 could be fed by a different combination of fuel and combustion agent, which could adapt to different situations and propulsion requirements, for example for satellites and space vehicles having larger sizes than those typical of the artificial satellites discussed previously: microsatellites, nanosatellites and picosatellites.

In case of vehicles with larger sizes, they could transport separate tanks of fuel and combustion agent, and in liquid phase, or under supercritical conditions, obtained by compression. These vehicles can include not only satellites but also space vehicles and launchers.

The typical combustion agent could be oxygen whereas the fuel could be a hydrocarbon like methane.

Solutions providing to feed liquid (or supercritical) fuels and combustion agents are also possible; for the first one it is possible to mention liquid hydrogen, kerosene, methanol or ethanol, dinitrogen tetroxide (hydrazine) whereas for the second ones it is possible to mention liquid oxygen, hydrogen peroxide, nitric compounds like nitric acid.

The combustion agent or the fuel requiring the larger range of flow expressed as mass per time unit is conveniently injected in the combustion chamber 10 by using the first injection duct 15, that is the tangential injection duct, whereas the combustion agent or the fuel requesting the smaller range of flow can be injected through the second injection duct 16, that is the perpendicular injection duct, so as to impose to their combination reacting in the combustion chamber a path with helical shape near the inner cylindrical surfaces of the combustion chamber 10.

At said second end 14 of the combustion chamber 10, the propulsion system comprises a sub-supersonic nozzle 20, as discharge of the combustion chamber 10, with a discharge duct 19 which connects it thereto positioned tangential to the cylindrical walls of the chamber 10 and it is arranged parallel to the plane of the second end 14. The position of the discharge duct 19 is so that it receives the above-mentioned helical motion of the flow of the reactant gases which, in the starting example, are water vapour.

The direction of such flow to the discharge duct 19 is the correct one to minimize the pressure drops in this point of the circuit.

The shape of the supersonic nozzle 20 is so as to optimize the expansion of the hot gases existing inside the combustion chamber 10, therefrom it is possible to obtain the thrust necessary for the mission targets.

In the light of what described, it is important to underline that the transportation of liquid water involves very reduced volumes, it does not require any cunning device in terms of safety and it does not require tanks with particular technical features.

Moreover, the electrolytical process, for the division of water into gaseous hydrogen and oxygen, requires low amounts of energy, which can be obtained easily by means of solar cells even with very small sizes.

The gaseous hydrogen and oxygen are the pair of fuel/combustion agent having the highest performance; the electrolytical process divides the water into oxygen and hydrogen in the optimum stoichiometric proportions which, nominally, provide the best performance with consequent production of only water vapour outgoing from the chamber.

In addition to this, the catalytic deposition, together with the helical fluid dynamics motion inside the combustion chamber, allows to simplify, until totally eliminating, the ignition system, and to reduce to the minimum the required minimum sizes of the chamber in order to have an effective combustion.

Preliminary analyses detect, in order to obtain a thrust of 10 N, global sizes of the propulsion system smaller than 13m m, with a micro-nozzle which allows to obtain high thrusts in very reduced sizes.

By referring to figure 5, a propulsion system is schematically illustrated and described wherein there is one single tangential injection duct, designated with 15, in the combustion chamber 10. Then it can be fed with a fuel-combustion agent mixture suitably selected based upon the operating needs of the satellite or of the vehicle.

In this example, the injection duct 15 is fed by an electrolyser 2 which was placed inside a tank 30 of water; the electrolyser 2 is fed electrically and produces gaseous H_2 and O_2 inside the tank 30.

The produced gases are kept separated from the liquid water by the spinning of the satellite, or of the vehicle, and then are introduced, already premixed in the right stoichiometric proportion, into the combustion chamber 10 through the single injection duct 15.

The ignition of the premixed gas can take place by means of an electric spark, or spontaneously by means of catalysis (for example platinum on the inner walls of the chamber). The catalysis in case can support the ignition by means of the spark as in the previous example.

To the above-described propulsion system, a person skilled in the art, with the purpose of satisfying additional and contingent needs, could introduce several additional modifications and variants, however all within the protective scope of the present invention, as defined by the enclosed claims.

CLAIMS

1. A space propulsion system (1), comprising:

- a combustion chamber (10) implemented by a cylindrical container (11) having cylindrical walls (13), a first end (12) provided at least with an injection duct (15) for a combustion agent, a fuel and/or a mixture thereof, for the injection according to a direction tangential to said cylindrical walls so as to induce a helical combustion path in the combustion chamber (10), a possible additional injection duct (16) for a fuel or a combustion agent in direction perpendicular to said cylindrical walls, and an opposite end (14) provided with a discharge duct (19) arranged according to a direction tangential to said cylindrical walls (13) so as to receive and direct said helical path, wherein the cylindrical walls have a deposition of catalytic material inside thereof, for accelerating the combustion reaction; and
- a supersonic nozzle (20), connected to said discharge duct (19) for discharging the combustion products in the combustion chamber.

2. The space propulsion system (1) according to claim 1, comprising an electrolytic system (2), fed by an electric source (6), for the division of water into oxygen and hydrogen and for their injection in the tangential injection duct and in the additional injection duct, respectively.

3. The space propulsion system (1) according to claim 1, comprising a water tank (30) thereto an electrolytic system (2) is associated, fed by an electric source (6), for the division of water into oxygen and hydrogen and for their injection in the tangential injection duct and in the additional injection duct, respectively.

4. The space propulsion system (1) according to claim 1, comprising a water tank (30) having an electrolytic system (2) inside thereof, fed by an electric source (6), for the division of water into oxygen and hydrogen and for their injection in a mixture in the tangential injection duct.

5. The propulsion system (1) according to claim 2 or 3, wherein the electrolytic system (2) feeds respective oxygen

tank (7) and hydrogen tank (8), connected to the combustion chamber by suitable valves (17, 18).

6. The propulsion system (1) according to claim 5, wherein the electrolytic system (2) has two branches respectively with an anode (4) and a cathode (5), for bubbling gaseous oxygen and hydrogen separately.

7. The propulsion system (1) according to anyone of the preceding claims, wherein said electric source comprises a battery (6).

8. The propulsion system (1) according to claim 1, wherein the combustion chamber (10) comprises a cylindrical container (11) having a first flat end (12) thereat there are two injection ducts (15, 16) a first duct thereof is tangential and parallel to said first end (12).

9. The propulsion system (1) according to claim 8, wherein a second injection duct (16) is perpendicular to the cylindrical walls (13) of the combustion chamber (10), parallel to the plane of the first end (12), the position of the second injection duct (16) being such that the inlet in the combustion chamber (10) takes place near the inlet of the first duct (15), so that the gaseous flow injected through the first duct (15) intersects the gaseous flow injected through the second duct (16).

10. The propulsion system (1) according to claim 1, wherein said deposition of catalytic material comprises mainly Platinum.

11. The propulsion system (1) according to claim 1, wherein said deposition of catalytic material is so as to allow the ignition of the combustion reaction with development of flame without potentially any outer ignition intervention.

12. The propulsion system (1) according to claim 1, wherein the combustion chamber (10) is implemented as one single piece, and it has only the openings necessary to the injection and discharge.

AMENDED CLAIMS
received by the International Bureau on 19 December 2018 (19.12.2019)

1. A space propulsion system (1), comprising:

- a combustion chamber (10) implemented by a cylindrical container (11) having cylindrical walls (13), a first end (12) provided at least with an injection duct (15) for a combustion agent, a fuel and/or a mixture thereof, for the injection according to a direction tangential to said cylindrical walls so as to induce a helical combustion path in the combustion chamber (10), a possible additional injection duct (16) for a fuel or a combustion agent in direction perpendicular to said cylindrical walls, and an opposite end (14) provided with a discharge duct (19) arranged according to a direction tangential to said cylindrical walls (13) so as to receive and direct said helical path; and
- a supersonic nozzle (20), connected to said discharge duct (19) for discharging the combustion products in the combustion chamber.

2. The space propulsion system (1) according to claim 1, wherein the cylindrical walls have a deposition of catalytic material inside thereof, for accelerating the combustion reaction.

3. The space propulsion system (1) according to claim 1, comprising an electrolytic system (2), fed by an electric source (6), for the division of water into oxygen and hydrogen and for their injection in the tangential injection duct and in the additional injection duct, respectively.

4. The space propulsion system (1) according to claim 1, comprising a water tank (30) thereto an electrolytic system (2) is associated, fed by an electric source (6), for the division of water into oxygen and hydrogen and for their injection in the tangential injection duct and in the additional injection duct, respectively.

5. The space propulsion system (1) according to claim 1, comprising a water tank (30) having an electrolytic system (2) inside thereof, fed by an electric source (6), for the division of water into oxygen and hydrogen and for their injection in a mixture in the tangential injection duct.

6. The propulsion system (1) according to claim 3 or 4, wherein the electrolytic system (2) feeds respective oxygen tank (7) and hydrogen tank (8), connected to the combustion chamber by suitable valves (17, 18).

7. The propulsion system (1) according to claim 6, wherein the electrolytic system (2) has two branches respectively with an anode (4) and a cathode (5), for bubbling gaseous oxygen and hydrogen separately.

8. The propulsion system (1) according to anyone of the preceding claims, wherein said electric source comprises a battery (6).

9. The propulsion system (1) according to claim 1, wherein the combustion chamber (10) comprises a cylindrical container (11) having a first flat end (12) thereat there are two injection ducts (15, 16) a first duct thereof is tangential and parallel to said first end (12).

10. The propulsion system (1) according to claim 9, wherein a second injection duct (16) is perpendicular to the cylindrical walls (13) of the combustion chamber (10), parallel to the plane of the first end (12), the position of the second injection duct (16) being such that the inlet in the combustion chamber (10) takes place near the inlet of the first duct (15), so that the gaseous flow injected through the first duct (15) intersects the gaseous flow injected through the second duct (16).

11. The propulsion system (1) according to claim 1, comprising means for the ignition of said combustion agent, fuel and/or mixture thereof, comprising a deposition of catalytic material.

12. The propulsion system (1) according to claim 1, comprising means for the ignition of said combustion agent, fuel and/or mixture thereof, comprising means for flashing an ignition spark.

13. The propulsion system (1) according to claim 2 or 11, wherein said deposition of catalytic material comprises mainly Platinum.

14. The propulsion system (1) according to claim 1, wherein the combustion chamber (10) is implemented as one single piece, and it has only the openings necessary to the injection and discharge.

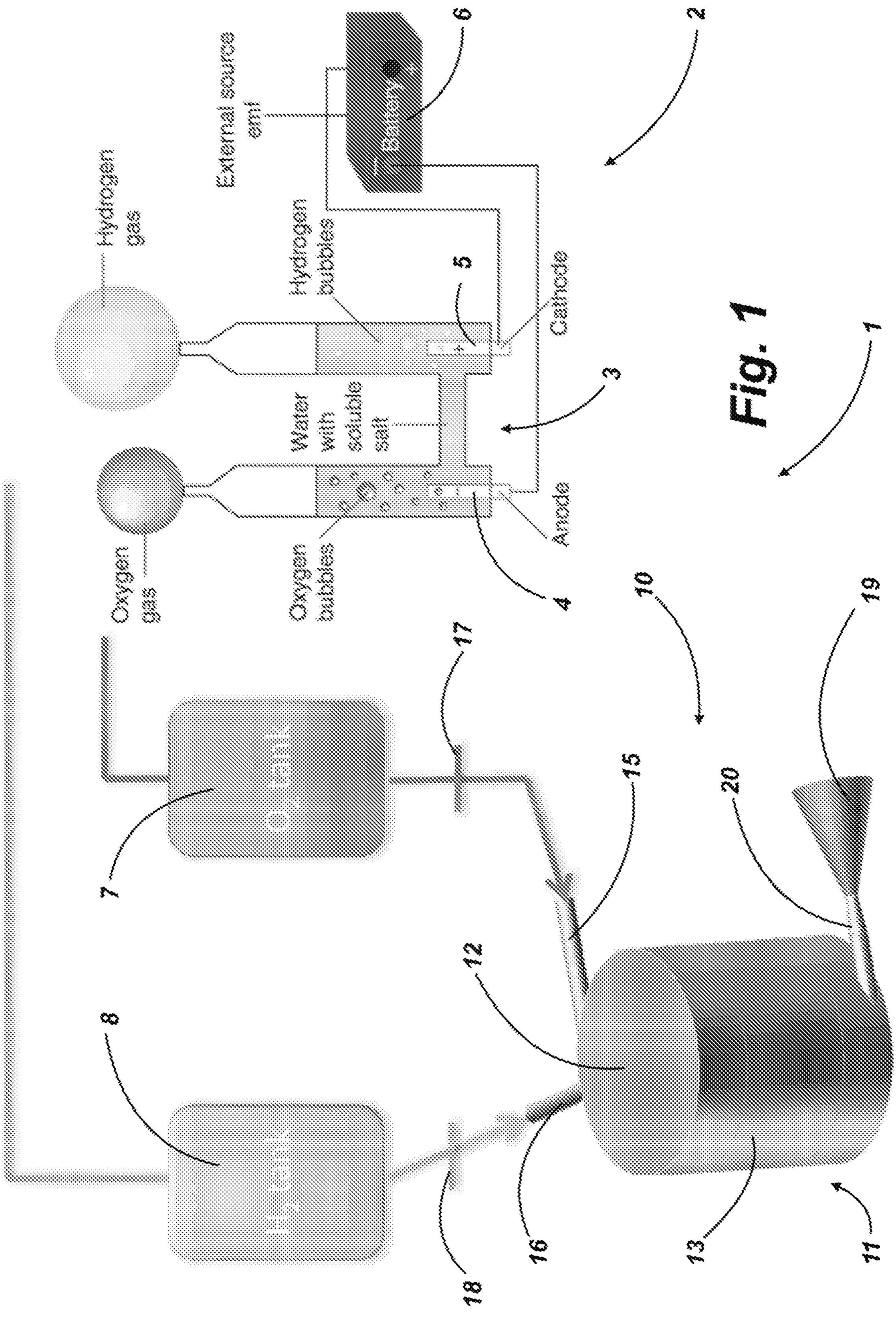
Hydrogen gas
Oxygen gas
Hydrogen bubbles
Oxygen bubbles
Water with soluble salt
Cathode
Anode
External source emf
Battery
O_2 tank
H_2 tank
1
2
3
4
5
6
7
8
10
11
12
13
15
16
17
18
19
20

Fig. 1

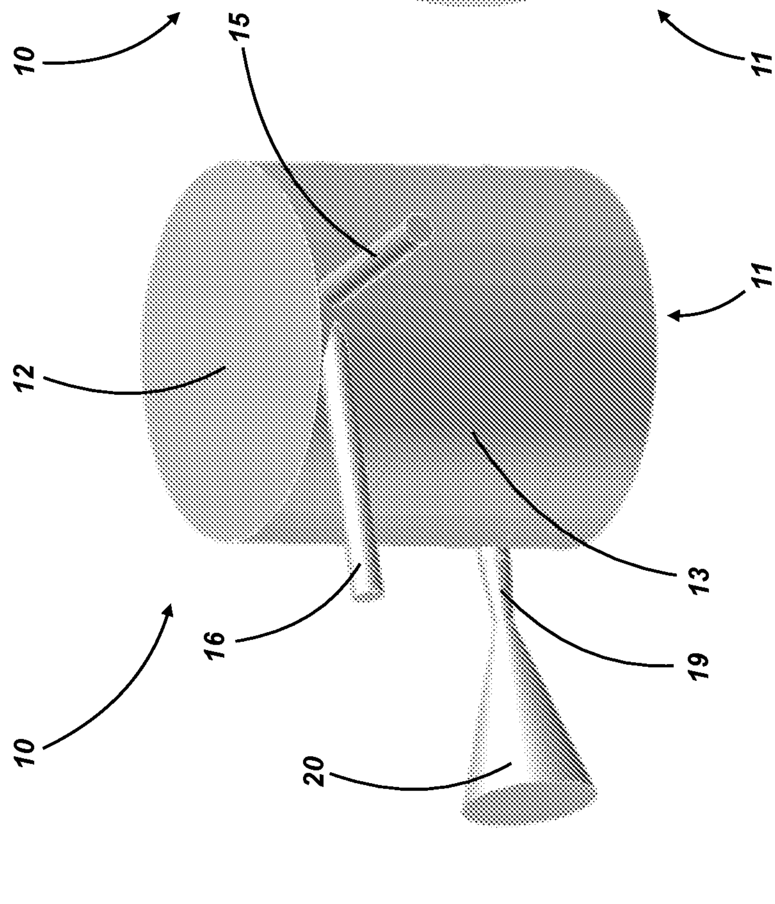

Fig. 2

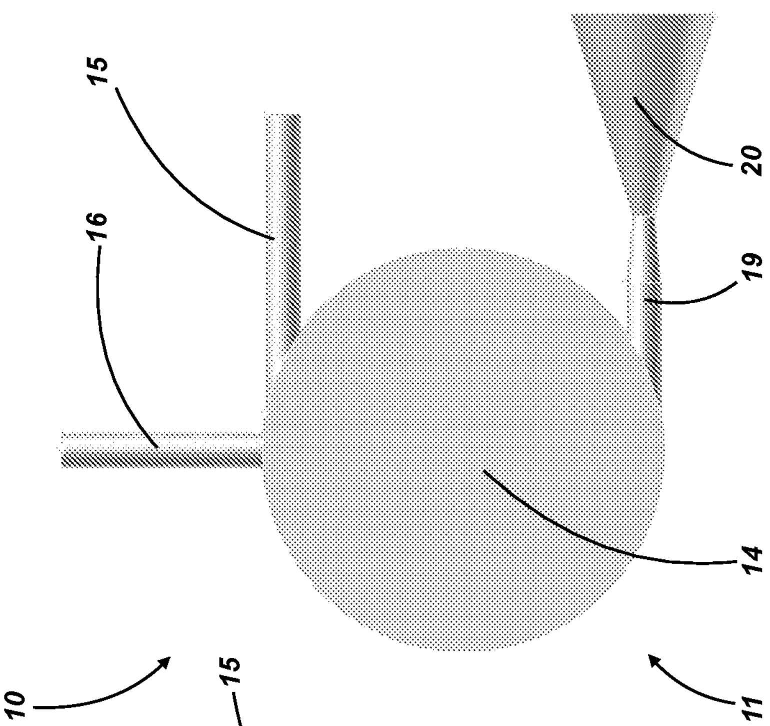

Fig. 3

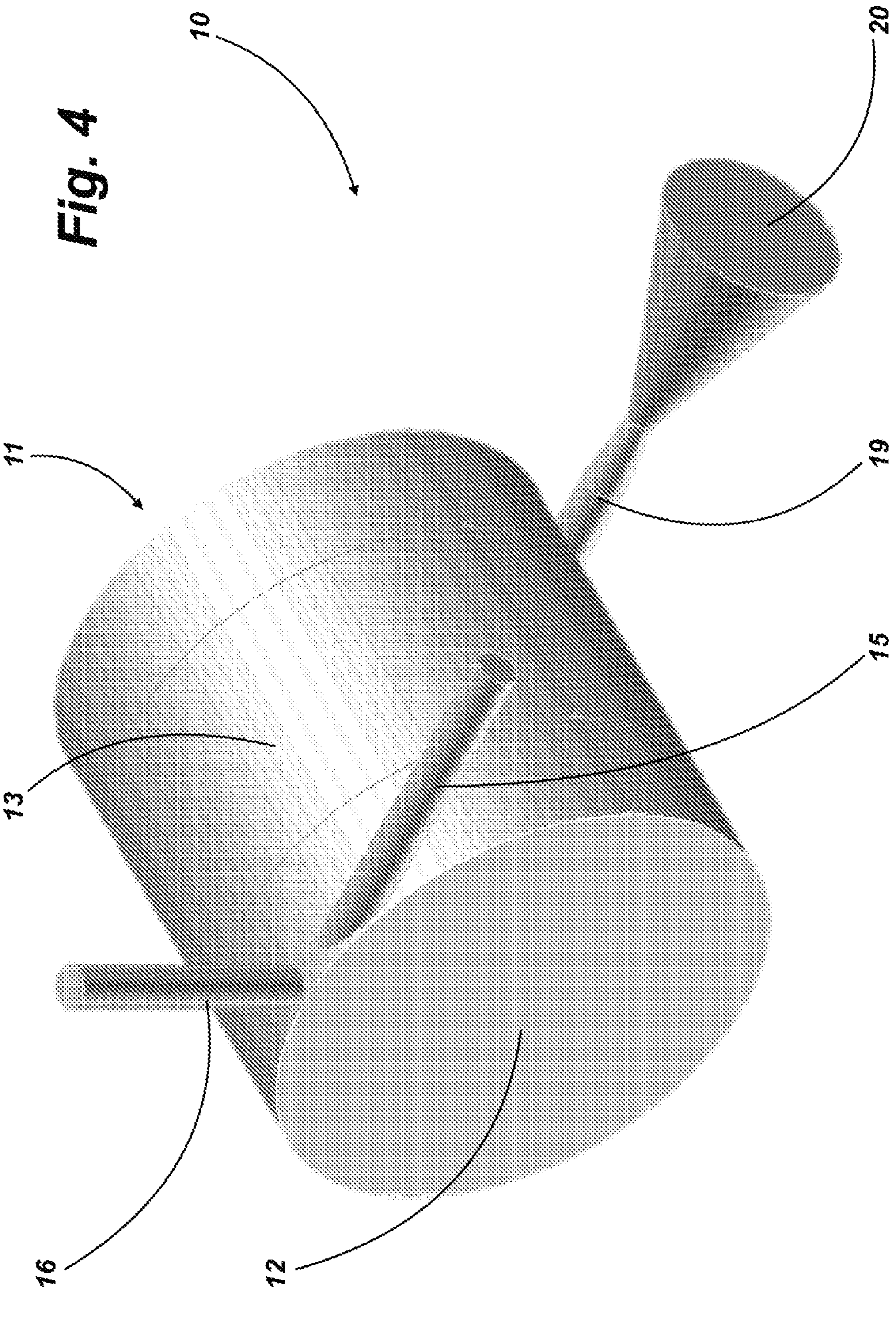

Fig. 4

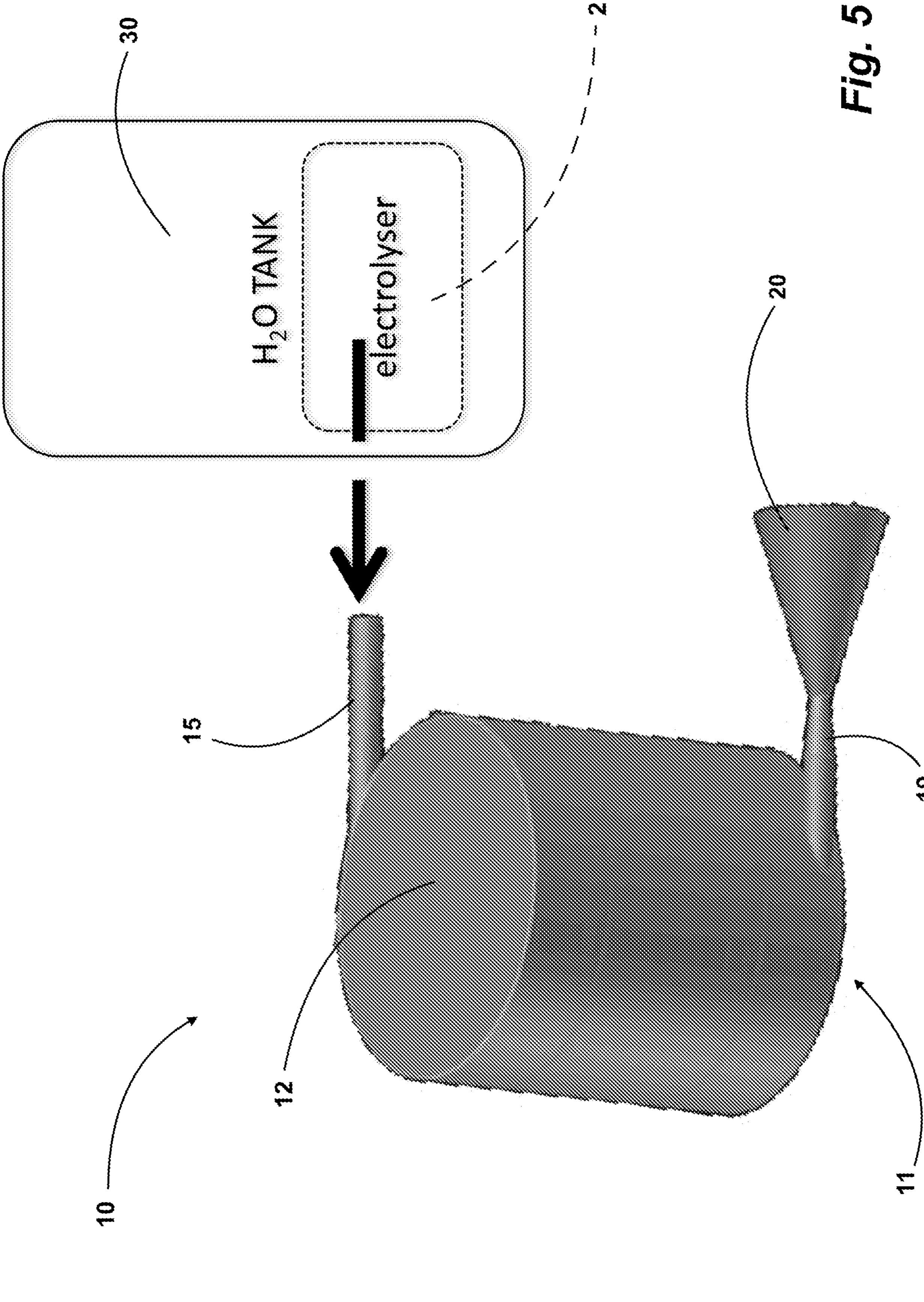

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2018/055595

A. CLASSIFICATION OF SUBJECT MATTER
INV. F02K9/42 F03H99/00 F02K99/00 F02K9/62
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F02K F03H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2016/116450 A2 (COMMISSARIAT À L ÉNERGIE ATOMIQUE ET AUX ÉNERGIES ALTERNATIVES [FR]; U) 28 July 2016 (2016-07-28) page 7, line 24 - page 8, line 11 page 9, lines 18-20; claim 1; figures 1A,1B -----	1-12
Y	US 3 490 235 A (GRANT DANIEL J) 20 January 1970 (1970-01-20) column 2, line 33 - column 3, line 15; figure 1 -----	1-12
A	US 4 345 729 A (BARTER ARTHUR J) 24 August 1982 (1982-08-24) column 2, lines 1-36; figure 1 ----- -/--	1-10

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 November 2018	19/11/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Steinhauser, Udo

Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3 517 508 A (NEWMAN DANIEL D ET AL) 30 June 1970 (1970-06-30) column 3, line 32 - column 4, line 53 column 6, lines 17-43	1-10
A	US 2 721 788 A (SCHAD JAMES L) 25 October 1955 (1955-10-25) column 2, lines 39-69	1-12
A	DE 41 22 755 A1 (ERNO RAUMFAHRTTECHNIK GMBH [DE]) 21 January 1993 (1993-01-21) column 3, line 53 column 4, lines 34-47	1-12

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2018/055595

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
WO 2016116450	A2	28-07-2016	EP	3247940	A2	29-11-2017
			FR	3031796	A1	22-07-2016
			WO	2016116450	A2	28-07-2016
US 3490235	A	20-01-1970	NONE			
US 4345729	A	24-08-1982	NONE			
US 3517508	A	30-06-1970	DE	1248374	B	24-08-1967
			FR	1444982	A	08-07-1966
			GB	1076485	A	19-07-1967
			US	3517508	A	30-06-1970
			US	3520137	A	14-07-1970
US 2721788	A	25-10-1955	NONE			
DE 4122755	A1	21-01-1993	DE	4122755	A1	21-01-1993
			EP	0535304	A1	07-04-1993
			US	5319926	A	14-06-1994