(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 101 642 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
07.12.2016 Bulletin 2016/49

(51) Int Cl.:
G08G 5/00 *(2006.01)*

(21) Application number: **15170063.0**

(22) Date of filing: **01.06.2015**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
MA

(71) Applicant: **Airbus Defence and Space GmbH**
85521 Ottobrunn (DE)

(72) Inventors:
- **de Oliveira, Rafael Fernandes**
  81675 München (DE)
- **Oberhauser, Matthias**
  81373 München (DE)
- **Mamessier, Sébastien**
  81549 München (DE)
- **Dreyer, Daniel**
  85411 Hohenkammer (DE)

(74) Representative: **Kastel, Stefan et al**
Kastel Patentanwälte
St.-Cajetan-Straße 41
81669 München (DE)

(54) **METHOD FOR DETERMINING REACHABLE AIRPORTS BASED ON THE AVAILABLE ENERGY OF AN AIRCRAFT**

(57) The invention refers to a method for determining airports in an available range of an aircraft, comprising the steps of: determining the available energy of the air-craft; calculating the energy consumption for a first flight route to a first airport; calculating the energy con-sumption when the aircraft heads in a second direction other than the flight direction of the first flight route; cal-culating the maximum range of the aircraft in the second direction; and determining whether a second airport is located in the second direction within the maximum range.

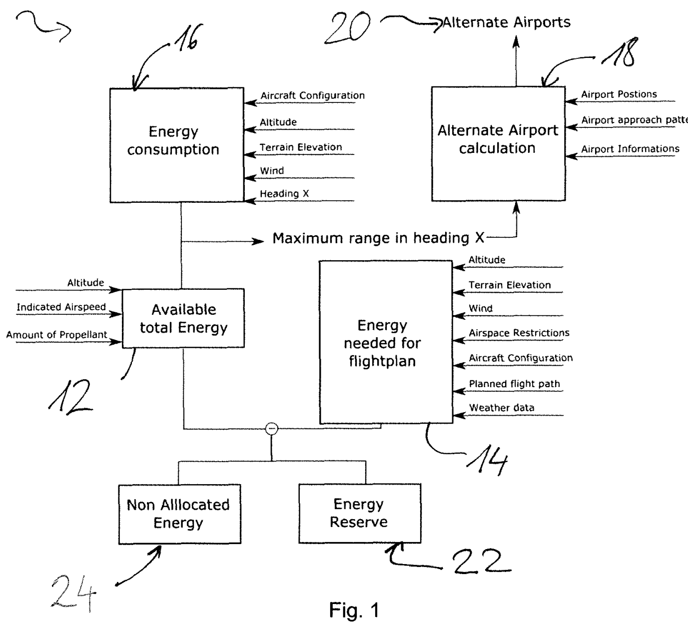

Fig. 1

EP 3 101 642 A1

Description

[0001] The invention relates to a method for determining airports and/or waypoints in an available range of an aircraft. The method comprises the steps of determining the available energy of the aircraft and calculating the energy consumption for the first flight route to a first airport.

[0002] For flying an aircraft, knowledge about the available energy is crucial because the energy has a huge impact on the long term (strategic) flight planning as well as the short term (tactical) flying. It determines the available range, the possible flight level that is reachable within a given flight plan and the possibility to divert from the flight plan because of external factors.

[0003] Energy can neither be destroyed nor created. It only can be transformed from one form of energy to another; for example, potential energy can be transformed into kinetic energy by descending the aircraft. By adding thrust, energy stored in the aircrafts propellant (chemical energy in the fuel or electrical energy stored in the aircrafts battery) can be transformed into kinetic energy by accelerating or potential energy by climbing.

[0004] Three forms of energy are especially relevant for flying an aircraft, namely potential energy (the aircraft's altitude), kinetic energy (the aircraft's speed), and propellant energy (chemical or electrical).

[0005] In aviation, kinetic energy is relevant for a short term (tactical) view, as it is lost quickly due to the higher aircraft's drag in high-speed (i.e. non-optimal aerodynamics) situations. Potential energy and the propellant energy are important for long term planning (strategic). Both forms of energy determine the actual range of the aircraft. With a high altitude and no propellant, a destination can still be reached by powerless gliding depending on the aerodynamics of the aircraft. It is important to keep in mind that the potential energy is linked with the elevation of the terrain. While flying over high terrain, the "usable" potential energy decreases as the distance to the ground is important. With sufficient propellant, an aircraft can maintain the current altitude and can reach destinations in a certain range without the need for transforming potential energy.

[0006] The possible range of an aircraft mainly depends on the factors energy, wind, and terrain.

[0007] In addition to these factors, operational factors like airspace and flight level restrictions decrease the possible range as well.

[0008] A management of flight energy is discussed for example in Merkt, Juan R. (2013) "Flight Energy Management Training: Promoting Safety and Efficiency,"Journal of Aviation Technology and Engineering: Vol. 3: Iss. 1, Article 6. http://dx.doi.org/ 10.7771/ 2159-6670.1072.

[0009] The objective of the invention is to provide a system that allows a pilot of an aircraft to quickly check alternative flight destinations.

[0010] The objective is solved by the method according to claim 1.

[0011] Preferred embodiments of the method are described in the dependent claims.

[0012] According to the invention, the method for determining airports and/or waypoints in an available range of an aircraft comprises the steps of:

a) Determining the available energy of the aircraft;
b) Calculating the energy consumption for a first flight route to a first airport;
c) Calculating the energy consumption when the aircraft heads in a second direction other than the flight direction of the first flight route;
d) Calculating the maximum range of the aircraft in the second direction; and
e) Determining whether a second airport and/or a waypoint is located in the second direction within the maximum range.

[0013] The aircraft is preferably a plane that is powered by a propellant such as fuel like kerosene or by electrical energy stored for example in batteries.

[0014] The maximum range of the aircraft preferably is the distance that the aircraft can cover using the energy that is totally available in the aircraft.

[0015] Waypoints are preferably certain locations along the flight route that must be either overflown and/or from which diversions from the actual flight route can be made.

[0016] In step a), the available energy of the aircraft is calculated. The calculation of the available energy is preferably performed based on measurements of the different types of energies that are available to the aircraft. For example, sensors can be employed to determine various aspects of the aircraft. The results of the measurements of the sensors are then collected, preferably in a central processing unit in order to calculate the available energy. The calculation is preferably done using models which are tested in previous flights.

[0017] In step b), the energy consumption for the first flight route to a first airport is calculated. The first airport may be the desired destination of the aircraft. The first flight route preferably is the route from the current position of the aircraft to the desired destination, i.e. the first airport. The energy consumption is calculated based on models which preferably incorporate a plurality of parameters that characterize the energy needed for driving the aircraft. Hence, the energy consumption is equivalent to the energy required for driving the aircraft along the first flight route to the first airport. Preferably, the models used for calculating the energy consumption or the energy required for the first flight route are based on models that are tested in previous flights of the aircraft. Such models are for example known in the prior art such that further discussion is not required.

[0018] In step c), the energy consumption is calculated when the aircraft heads in a second direction. The second direction is a direction that differs from the current direction or the flight direction of the aircraft. The current direction or flight direction preferably varies along the first flight route. Preferably, the second direction also varies along the flight route. Preferably, the calculation of the energy consumption or the energy needed for driving the aircraft along the second direction is performed based on the same models as calculating the energy consumption for the first flight route.

[0019] The second direction is preferably a straight direction meaning that, for the calculation purposes of step c), it is assumed that the aircraft is heading straight along the second direction. Alternatively, predetermined flight patterns can be used instead of the straight flight route that is assumed for the second direction. Hence, depending on whether certain flight patterns or the straight flight route are used for the second direction, the energy consumption may vary.

[0020] In step d), the maximum range of the aircraft in the second direction is calculated, preferably based on the calculated energy consumption determined in step c). Thus, the information is available how far the aircraft can fly along the second direction. Preferably, the calculation of the maximum range is done using the same technique as calculating the energy consumption along the first flight route.

[0021] In step e), it is determined whether a second airport is located in a second direction within the maximum range. Alternatively or additionally, it is checked whether a waypoint is located in the second direction within the maximum range. Preferably, the second airport and/or the waypoint are known from databases from which the position of the second airport and/or the waypoints in relation to the composition of the airport can be determined. It is preferred that the second direction is chosen such that the second direction points to the second airport and/or the waypoint. In step e), it may be checked whether the maximum range is greater than the distance between the current position of the aircraft and the second airport and/or the waypoint. If this is the case, the second airport and/or the waypoint may be made available to the pilot as an alternative destination. This may be done by an acoustic or visual signal. For example, the name and/or the distance to the second airport and /or the waypoint may be displayed to the pilot.

[0022] Preferably, the waypoint determined in step e) does not lie on the first flight route.

[0023] It is preferred that the steps c) to e) are repeated for a plurality of directions, wherein preferably the directions cover an angular range of 60°, 120°, 180°, or 360°.

[0024] Preferably, a third, fourth, fifth and so on directions are calculated and more preferably the third, fourth, fifth and so on directions point to the location of a third, fourth, fifth and so on airports. Additionally or alternatively, the directions preferably point to the location of different waypoints.

[0025] Preferably, all airports and/or waypoints that are theoretically in range of the aircraft may be used for calculating the energy consumption in the direction of these airports and/or waypoints, respectively, such that the pilot can be made aware of all possible airports and/or waypoints that are within the maximum range of the aircraft with regard to the available energy of the aircraft.

[0026] More preferably, the calculation of the energy consumption is made for all directions spanning a range of 360°. The maximum range in any direction may be displayed as a line surrounding a representation of the aircraft whereby the distance between the line and the representation of the aircraft represents the maximum range. In this embodiment, the locations of the first airport and the second airport may be depicted in this representation. All second airports are then located in the area circled by the line representing the maximum range whereas all airports that are not within the maximum range of the aircraft are outside the area surrounded by the line representing the maximum range of the aircraft in the second direction. Similarly, the position of waypoints that are reachable by the aircraft are alternatively or additionally depicted in this representation. The reachable waypoints are then surrounded by the line representing the maximum range.

[0027] It is preferred that step a) includes

a1) determining the amount of propellant stored in the aircraft and/or
a2) determining the altitude of the aircraft and/or
a3) determining the current speed of the aircraft.

[0028] Step a1) referring to the determination of the amount of propellants stored in the aircraft is preferably done using sensors. The sensors may detect the amount of fuel stored in a tank of the aircraft. Alternatively, the sensors measure the electrical energy stored in a battery of the aircraft. Based on the amount of fuel in the aircraft, the available energy can be calculated since the energy density or energy stored in the fuel is a known parameter.

[0029] Alternatively or additionally, the altitude of the aircraft is determined in step a2). The altitude of the aircraft represents the potential energy of the aircraft. The potential energy of the aircraft can be transformed in kinetic energy. For example, an aircraft cruising at a certain altitude can use this altitude for travelling the aircraft by gliding without using a propellant. The potential energy depends on the elevation of the terrain. Flying at the same height over low terrain and then over high terrain alters the potential energy which in turn decreases the available energy of the aircraft.

[0030] Alternatively or additionally, the current speed of the aircraft is determined in step a3). The current speed of the aircraft corresponds to the kinetic energy of the aircraft. Hence, the total energy of the aircraft comprises the kinetic energy, the potential energy, and energy that is stored in the aircraft. Based on these different types of energy, the available energy can be calculated and used for determining the maximum range of the aircraft. Models and algorithms for determining the maximum range of the aircraft based on the available energy are known in the prior art.

[0031] It is preferred that step b) and/or step c) includes

b1) determining the energy consumption depending on the altitude of the aircraft and/or
b2) determining the energy consumption with regard to planned flight path and/or air space restrictions; and/or
b3) determining the energy consumption based on the weather data, in particular the wind regime; and/or
b4) determining the energy consumption based on the configurations of the aircraft and/or
b5) determining the energy reserve and/or
b6) determining the non-allocated energy.

[0032] Preferably, the steps b1) to b6) are used both for calculating the energy consumption for flying along the first flight route and for flying along the second direction.

[0033] Hence, the same models or calculation methods can be applied for both steps which simplifies the implementation of the described method.

[0034] Step b1) refers to the determination of the energy consumption depending on the altitude of the aircraft. The altitude of the aircraft is preferably done using known sensors or appropriate measuring instruments.

[0035] The energy consumption depends strongly on the drag of the aircraft. The drag of the aircraft in turn varies considerably with the altitude of the aircraft since the density of the air varies along the altitude of the aircraft. Hence, in step b), the current or the future altitude of the aircraft - the altitude that is expected along the first flight route or along the second direction - is used as a parameter for determining the energy consumption. The drag of an aircraft depending on the altitude is a known value for the aircraft which can be measured beforehand.

[0036] Alternatively or additionally, the energy consumption is determined with regard to the planned flight path and/or airspace restrictions. For example, the planned flight path includes the predetermined pattern for the second direction, as discussed above. Possible restrictions may be caused by the elevation of the terrain such as mountains reaching high altitudes. Other restrictions may be constituted by airspace that is prohibited for flying through or being flown over. Airspace restrictions may cause to alter the flight route such that the planned flight path may be longer than the shortest connection between the current position of the aircraft and the first airport and/or the second airport. Flight space restrictions may also include that the aircraft is required to travel along certain predefined routes that are determined by the flight control.

[0037] Alternatively or additionally, the energy consumption is determined based on the weather data, in particular the wind regime, in step b3).

[0038] Flying with the wind direction or against the wind direction significantly changes the energy consumption of the aircraft. Hence, it is preferred that in the step of calculating the energy consumption the wind regime that is expected along the first flight route and/or along the second direction is included in determining the energy consumption. Other weather data, such as expected thunderstorms which may require to divert the aircraft or fog which may prevent or delay the landing at a certain airport, may also be included in the calculation of the energy consumption.

[0039] Alternatively or additionally, the energy consumption is determined based on the configurations of the aircraft in step b4). The configurations of the aircraft may include the size, the engine, and the net weight of the aircraft. The configurations of the aircraft are crucial for determining the energy consumption. Further configurations of the aircraft may include the added load, the number of passengers in the aircraft and so on. These factors are preferably also included in calculating the energy consumption. This can be done using models already available in the prior art.

[0040] Alternatively or additionally, the energy reserve is determined in step b5). The energy reserve is the energy that is not intended to be used on the normal circumstances such that the energy reserve may not be included in the energy that is available for determining the maximum range of the aircraft. Alternatively or additionally, the non-allocated energy is determined. The non-allocated energy may be shown to the pilot by means of a display. The non-allocated energy is for example the difference between the available energy and the energy that is required for flying along the first flight route. However, the non-allocated energy can be calculated for the second flight route as well. The non-allocated energy for the first flight route and the second direction may be also displayed which can be a decisive factor for the pilot when assessing whether to continue to fly to the first airport or change the destination to the second airport or use a different waypoint.

[0041] A preferred advantage of the invention is that the pilot is instantly aware of all possible alternative destinations or flight routes that are within the reach of the aircraft. Hence, the pilot may not need to worry whether certain airports are within the maximum range of the aircraft, but can rather focus on the best solution for reaching a certain destination.

[0042] In a further preferred advantage, the method be such that many and/or all parameters for determining the maximum range in a second direction are included in the calculation for the energy consumption. Hence, if all second airports that are within the distance of the maximum range are displayed to the pilot, the pilot is immediately aware of alternative destinations without the requirement to check whether the alternative destinations can actually be reached by the aircraft. Hence, the pilot may focus on the safest and simplest route for achieving a certain destination. In particular, the method utilizes all information that is available for the pilot such that the calculation of the maximum range can be safely used as a starting process for deciding the destination of the aircraft.

[0043] A preferred advantage of the invention is that waypoints that are not located on the first flight route may also be shown to the pilot. Thus, the pilot is preferably aware of alternative routes to the first airport, namely by using the alternative waypoints.

[0044] It is preferred that step f) includes determining a second flight route to the second airport, wherein the second flight route includes the airport approach pattern and/or airspace restrictions.

[0045] In the preferred additional step, the actual flight route to the second airport is determined. The second direction representing the shortest distance between the current position of the aircraft and the second airport is normally not the actual flight route since the airport approach pattern and/or airspace restrictions, as discussed above, may require to alter the actual flight route from the second direction. Thus, the second flight route may be longer than the second direction. Hence, it is preferably additionally checked whether the energy consumption needed for the second flight route is smaller than the available energy for the aircraft such that the aircraft can reach the second airport via the second flight route. The airport approach pattern may be a predefined route that an aircraft must follow in order to land at the airport. Aerospace restrictions which may affect the planning of the second flight route are discussed above.

[0046] It is preferred that step f) includes determining the energy consumption for the second flight route, wherein the determination of the energy consumption comprises

f1) determining the energy consumption depending on the altitude of the aircraft on the second flight route and/or
f2) determining the energy consumption based on the weather data, in particular the wind regime, for the second flight route; and/or
f3) determining the energy consumption based on the configurations of the aircraft and/or
f4) determining the energy reserve and/or
f5) determining the non-allocated energy.

[0047] Steps f1) to f5) correspond to steps b1) and b3) to b6). Hence, similar arguments apply.

[0048] It is preferred that step g) comprises

g1) determining the maximum range along the second flight route based on the energy consumption of the second flight route and/or
g2) checking whether the second airport is within the maximum range of the second flight route.

[0049] A preferred advantage of steps g1) and g2) is that a pilot is immediately aware of the fact that the second airports that are preferably displayed to the pilot are actually within reach of the aircraft when flying the actual flight route to the second airports. In this calculation, all parameters affecting the energy consumption are preferably included such that the pilot can rely on the information that the second airports are actually within the available range of the aircraft.

[0050] It is preferred that a step h) includes determining an alternative flight route to the first airport, wherein the alternative flight route uses the waypoints that are different to the waypoints of the first flight route.

[0051] In the preferred additional step, an alternative flight route to the first airport is determined, namely by flying over waypoints that are different to the waypoints of the first flight route.

[0052] The second direction representing the shortest distance between the current position of the aircraft and the waypoint may not include the distance form the waypoint to the first airport or via further waypoints to the first airport. Thus, the alternative flight route may be longer than the first flight route. Hence, it is preferably additionally checked whether the energy consumption needed for the alternative flight route is smaller than the available energy for the aircraft such that the aircraft can reach the first airport via the alternative flight route.

[0053] It is preferred that step h) includes determining the energy consumption for the alternative flight route, wherein the determination of the energy consumption comprises

h1) determining the energy consumption depending on the altitude of the aircraft on the alternative flight route and/or
h2) determining the energy consumption based on the weather data, in particular the wind regime, for the alternative flight route; and/or
h3) determining the energy consumption based on the configurations of the aircraft and/or
h4) determining the energy reserve and/or
h5) determining the non-allocated energy.

[0054] Steps h1) to h5) correspond to steps f1 to f5). Hence, similar arguments apply.

[0055] It is preferred that step i) comprises

i1) determining the maximum range along the alternative flight route based on the energy consumption of the alternative flight route and/or
i2) checking whether the first airport is within the maximum range along the alternative flight route.

[0056] A preferred advantage of steps i1) and i2) is that a pilot is immediately aware of the fact that the first airport can be reached using one or more flight routes different to the first flight route. In this calculation, all parameters affecting the energy consumption are preferably included such that the pilot can rely on the information that the first airport can be reached using the alternative flight route.

[0057] Preferably, several alternative flight route are calculated wherein each alternative flight route includes a combination of waypoints that is different to the waypoints of the first flight route. For example, the alternative flight route has one waypoint in common with the first flight route however differs in two waypoints.

[0058] A further separate aspect of the invention refers to the representation of the available energy which may be connected to method of claim 1 and/or to its preferred embodiments.

[0059] It is preferred that available energy of the aircraft is represented by a bar, wherein preferably the bar is divided along a first axis into the energy consumed so far and/or the energy allocated for the first flight route and/or the non-allocated energy and/or the energy reserve.

[0060] Preferably the bar is displayed in a display or screen arranged in the cockpit of the aircraft such that a pilot can see the available energy. The bar may have the shape of a rectangular wherein one edge of the bar corresponds to a first axis representing the amount of energy. Along the first axis, the bar may be divided in the energy that is consumed so far, the energy that is allocated for the first flight route, the non-allocated energy and the energy reserved. Hence, the pilot sees the current energy situation for the first flight route at first glance.

[0061] Preferably, at one side of the bar, the current consumption of energy is displayed, preferably along with an optimum energy consumption. Additionally, it can be displayed whether the available energy increases, for example by charging the battery.

[0062] It is preferred that the altitude of the aircraft is represented along a second axis of the bar, wherein preferably the available energy is represented over the first axis.

[0063] The representation of the altitude of the aircraft along a second axis, that is preferably perpendicular to the first axis, shows to the pilot at one glance both the energy that is available from the propellant and the potential energy. Hence, the pilot has an improved overview of the current energy situation of the aircraft.

[0064] It is preferred that at least one waypoint of the first flight route is represented on a first side of the bar along the first axis.

[0065] Waypoints are preferably certain locations along the flight route that must be either overflown and/or from which diversions from the actual flight route can be made. The representation of the waypoints preferably allows the pilot a better grasp of the chosen flight route and, in particular, at which position the aircraft is on the current flight route. Preferably, the waypoints are depicted solely at one side of the bar.

[0066] It is preferred that the second airport is represented on a second side of the bar along the first axis.

[0067] Preferably, the second airport which corresponds to an alternative flight route is represented opposite to the side where the waypoints referring to the actual flight route are represented. A preferred advantage of this embodiment is that the pilot sees the relation of the second airport with regard to the available energy at first glance. In particular, the pilot can better compare the distance to the waypoints of the actual flight route in comparison to the distance to the second airports.

[0068] It is preferred that airspace restrictions are represented in the bar.

[0069] Airspace restrictions may correspond to elevations in the terrain such as mountains. The height of the mountains is preferably depicted in the bar along the second axis. Similarly, airspace restrictions for regions that cannot be flown through may also be depicted in the bar, for example by rectangles.

[0070] It is preferred that the bar further includes a section along the first axis corresponding to distance which the aircraft can cover by gliding.

[0071] Preferably, the section corresponding to the distance which the aircraft can cover by gliding is only shown when the aircraft is consuming the propellant allocated to the reserve. Preferably, second airports are also depicted such that the pilot can see which of the airports can be reached by gliding.

[0072] It is preferred that the distance that can be covered by gliding is included for determining the maximum range of the aircraft.

[0073] A further separate aspect of the invention refers to an alternative or additional representation of the available energy which may be connected to method of claim 1 and/or to its preferred embodiments.

[0074] It is preferred that the maximum range in the second direction is represented by a first line spaced apart from a center point.

[0075] The center point may be depicted as an aircraft. The distance between the center point and the first line may correspond to the maximum range along the direction (the second direction) from the center point to the section of the line. Preferably, the maximum range is calculated spanning a range of 360° such that the center point is surrounded by the first line. Due to wind regimes, the first line may differ significantly from a circle.

[0076] The representation of the maximum range by a first line spaced apart from a center point may be additionally or alternatively used to the representation of the available energy represented by a bar.

[0077] It is preferred that the airspace restrictions are represented by areas and/or the first and/or the second flight routes are represented by a second line starting from the center point.

[0078] Preferably, the areas representing airspace restrictions are highlighted, for example by colors. Hence, the pilot sees at first glance which part of the surroundings of the aircraft cannot be flown through, for example due to the elevation of the terrain. Preferably, the second flight routes are also represented such that the pilot may see at first glance the actual route of the first flight route and the second flight route. This may help the pilot to decide which destination is chosen.

[0079] Another aspect of the invention refers to an energy management system for determining airports in a maximum range of an aircraft, comprising an energy calculation unit for determining the available energy of the aircraft, a first energy consumption calculation unit for calculating the energy consumption for a first flight route to a first airport; a second energy consumption calculation unit for calculating the energy consumption when the aircraft heads in a second direction other than the flight direction of the first flight route, an airport calculation unit that calculates the maximum range of the aircraft in the second direction, and an airport determination unit that determines whether an airport is located in the second direction within the maximum range.

[0080] Thus, this invention also refers to an energy management system that assists a pilot in efficiently managing his finite amount of energy in order to complete his mission. This system may calculate ranges according to several actual and hypothetical external and internal factors, assist planning routes according to energy aspects and external factors, and/or visualize the current energy state and possible destinations in case of an emergency.

[0081] The energy calculation unit preferably corresponds to step a) of the method, the first energy consumption calculation unit and the second energy consumption calculation unit may preferably correspond to steps b) and c), respectively of the method. The airport calculation unit may correspond to step d) and the airport determination unit may correspond to step e).

[0082] Preferably, all preferred embodiments of the method are also implemented in the energy management system described above.

[0083] A preferred embodiment of the invention is now discussed in conjunction with the attached drawings. Therein,

Fig. 1 shows an energy management system according to the invention;

Fig. 2 shows a representation of the available energy;

Fig. 3 shows an alternative representation of the available energy;

Fig. 4 shows another alternative representation of the available energy;

Fig. 5 shows a further representation of the available energy;

Fig. 6 shows another representation of the available energy; and

Fig. 7 shows a representation of the maximum range of the aircraft.

[0084] Fig. 1 shows a block diagram of an energy management system 10 of an aircraft. The energy management system 10 comprises an energy calculation unit 12, a first energy consumption calculation unit 14, a second energy consumption calculation unit 16, an airport calculation unit 18, an airport determination unit 20, an energy reserve determination unit 22 and a non-allocated energy determination unit 24.

[0085] The energy calculation unit 12 calculates the energy that is available to the aircraft. To this end, the altitude of the aircraft, the actual and/or expected speed of the aircraft and the amount of propellant of the aircraft are considered as factors for determining the available energy of the aircraft. The propellant may be the fuel that is stored in a tank of the aircraft or the electrical power stored in a battery of the aircraft. All parameter may be detected using sensors or other measuring instruments that are connected with the energy calculation unit 12. The altitude and the speed of the aircraft may also be determined using sensors that are connected with the available energy calculation unit 12. The energy calculation unit 12 may be constituted by a computer or any other control circuit that is capable of calculating the available energy based on the gathered values of the sensors.

[0086] The first energy consumption calculation unit 14 calculates the energy that is required for flying the aircraft along the first flight route. The first energy consumption calculation unit 14 may be also implemented by a computer or any other control circuit.

[0087] The energy consumption that is needed for flying along the first flight route to reach a first airport is calculated based on several parameters, such as the altitude of the aircraft, the terrain elevation, the wind, the airspace restrictions, the aircraft configuration, the planned flight path and weather data. The parameters may be processed using models for determining the energy required for flying the aircraft along the first flight route to the first airport. The models may be checked or trained, before they are used with the energy management system 10.

[0088] The second energy consumption calculation unit 16 calculates the energy that is needed for flying the aircraft along a second direction that differs from the first direction of the first flight route. The second energy consumption calculation unit 16 may determine the required energy based on several parameters such as the aircraft configuration, the altitude, the terrain elevation, and the second direction. The second energy consumption calculation unit 16 may be implemented by a computer or any other control circuit. The first 14 and second energy consumption calculation unit 16 may be identical.

[0089] The airport calculation unit 18 calculates the maximum range of the aircraft in the second direction. The airport calculation unit 18 may be implemented by a computer or any other control circuit. The airport calculation unit 18 may include not solely the route straight along the second direction but incorporates the actual flight route (the second flight route) to a second airport. To this end, the airport position, the airport approach pattern or other airport information are included for determining the second flight route. The maximum range in a second direction thus depends on the actual flight route to the second airport.

[0090] The airport determination unit 20 determines whether the available energy is sufficient for flying the aircraft along the second flight route to the second airport.

[0091] The energy reserve determination unit 22 automatically or manually indicates the amount of propellant that is allocated to the energy reserve. For example, the pilot manually inputs the propellant that is reserved for the energy reserve.

[0092] The non-allocated energy unit 24 determines the difference between the available energy of the aircraft and the sum of the energy reserve and the energy needed for the first flight route. The non-allocated energy unit 24 then puts forward the amount of energy that is not allocated. All units 12 to 24 are configured such that their information may be processed and displayed in a display.

[0093] Fig. 2 shows a representation of the available energy as a bar 26. The available energy is represented along a first axis D1. The first axis D1 of the bar 26 is divided in several sections. The bar 26 refers to an aircraft whose propellant is electrical energy stored in a battery. The battery charge is depicted along the first axis.

[0094] The first section labelled "Used" refers to the energy that is used so far. The second section is labelled "Mission" and refers to the energy that is needed for flying the aircraft along the first flight route. The third section labelled "NA" represents the non-allocated energy while the fourth section labelled "Reserve" refers to the energy allocated to the energy reserve.

[0095] At the one side of the bar 26, the current energy consumption is displayed using an arrow 28. If the arrow 28 points to the right, as shown in Fig. 2, energy is consumed. If the arrow 28 points to the left, energy is generated, i.e. the battery is charging.

[0096] Fig. 3 shows an alternative embodiment of the bar 26. Here again, the available energy is represented along the first axis D1. The altitude of the aircraft that is depicted as a triangle is represented along a second axis D2. This means, the higher the triangle is, the higher the altitude of the aircraft.

[0097] On a first side 30, the top side of the bar 26 in Fig. 3, waypoints of the first flight route and the first airport, labelled "Airport 1", are depicted. The line 34 represents the first flight route at a certain altitude. The connecting lines between the waypoints and the airport with the line 34 represent the waypoints and the airport along the first flight route.

[0098] On a second side 32 of the bar 26 opposite to the first side 30, second airports are shown. The second airports are labelled as "Airport 2" and "Airport 3". The lines starting from the second airports indicate the position of the second airports along the first flight route.

[0099] Fig. 4 shows an alternative representation of the bar 26. The bar 26 of Fig. 4 is identical to the bar 26 of Fig. 3, except that the elevation of the terrain is shown as line 36 in Fig. 4. Since the elevation of the terrain is higher than the first flight route, a change in the first flight route needs to be made. This change in the flight route can be seen in the dashed line 38 of Fig. 5. The alternative first flight route shows a change in the altitude of the aircraft, such that the energy required for reaching a first airport increases. This can be seen in that the airport of the alternative first flight route is moved to the right or, in other words, the representation of the first flight route is stretched (the dashed line 38 is longer than the line 34).

[0100] Airspace restrictions are shown in the bar 26 by a dashed rectangular 37 as for example shown in Fig. 4. The airspace restriction shown in Fig. 4 corresponds to an area that is prohibited to be flown in a certain altitude.

[0101] Fig. 6 shows an enlarged section of the bar 26, namely the reserve. Additionally to the bar 26 of Figs. 3 to 5, a section is added which represents a gliding phase of the aircraft, that is when no propellant is left. This is shown in Fig. 6 by the fact that the charge of the battery is zero. On a second side 32, a further second airport, labelled "Airport 4", is depicted which can be reached within the gliding. This detailed depiction can be shown automatically to the pilot when the available propellant/battery is within the reserve margin.

[0102] Fig. 7 refers to a representation of the maximum range of the aircraft. The aircraft depicted in Fig. 7 can be also called center point 40. A first line 42 surrounds the center point and represents the maximum range of the aircraft in the direction to the respective part of the first line 42. In the example given in Fig. 7, the first line 42 differs from a circle as on the bottom half are elevated terrains, such as mountains which cannot be overflown with the available energy of the aircraft. Hence, the distance between the center point 40 and the first line 42 varies along the angular range.

[0103] Airspace restrictions are depicted in Fig. 7 as areas 44. The areas 44 are highlighted such that the pilot can immediately see which part of the surrounding of the aircraft cannot be flown through.

[0104] Furthermore, a second line 46 is represented in the display shown in Fig. 7. The second line 46 shows the first flight route to the first airport. Hence, where the second line 46 ends, the first airport is located.

[0105] An alternative description of the figures is provided in the following.

[0106] Fig.1 shows the architecture of the energy management system. The available total energy is calculated based on the aircraft's current speed (kinetic energy), the altitude (potential Energy), and the amount of propellant (chemical or electrical energy). The energy that is needed for the current flight plan (first flight route) depends on several external and internal factors. The current altitude, the terrain elevation, and new airspace restrictions determine if a diversion in the flight plan is necessary (e.g. flying over a mountain top or a diversion due to an airspace restriction on a short notice). The wind that determines the ground speed is also an important factor; with strong headwinds more energy is needed to reach the destination. The energy that is needed for the flight plan and a safety margin can be subtracted from the currently available energy. This leads to a non-allocated amount of energy that can be used for adding changes to the flight plan (e.g. additional waypoints).

[0107] Based on the information provided by the available total energy calculation (energy calculation unit 12), an assumption on the possible range of the aircraft, independent from the current flight plan can be provided. Therefore, the terrain elevation and wind information in one heading direction (the second direction) is taken into account for calculating the possible range in this heading. By doing this for multiple heading probes (0° to 360°), an area of reachable points can be generated. By comparing this information with an airport database, a list of alternate airports can be generated.

[0108] In the following section, some visualizations for the energy management system are presented. All these visualizations are specific for an all electrical aircraft, but would also be suitable for conventional aircraft.

[0109] Fig. 2 shows a simplified indication bar 26 that shows the battery state. Several sections of the bar 26 indicate the energy that is used, the energy that will be used by the mission, the non-allocated energy and reserve energy of 10%. In addition, a trend indicator shows the speed at which the energy decreases or increases (e.g. in case of charging the aircraft on ground).

[0110] This display is used for a "quick glance". It is located near or inside the primary flight display.

[0111] A more long term strategic visualization is shown in Fig. 3. This display consists of three layers: A mission layer on top on the first side 30, a vertical energy indication (similar to the previous energy bar 26), and an alternate layer on the bottom (i.e. on the second side 32). The horizontal X-axis (first axis D1) represents the battery energy in whereas the vertical Y-axis (second axis D2) represents the potential energy. The whole X-axis represents the flight plan or mission. An indicator represents the current battery level. This indicator moves to the left as the flight continues.

[0112] In the Mission Layer, all the waypoints and the destination of the flight plan are represented. The necessary energy to reach a waypoint is represented by the distance from the current battery level to the waypoint. If a waypoint is more to the right - more energy is needed to reach it.

[0113] The vertical energy indicator shows the used energy, the energy needed for the mission, the non-allocated energy and the reserve. In addition, there is a vertical flight path indication that resembles the potential energy of the flight path.

[0114] The Alternate Layer on the bottom has information on alternative airports that are reachable from the current aircraft position. This way the pilot is aware of the energy distance of the alternative airports at any given time. Due to wind, terrain, or airspace constraints, it is possible that the closest airport is not the best choice in terms of consumed energy. The airports that are shown in the alternate layer can be selected and a flight path suitable to reach this airport is calculated automatically.

[0115] In addition to the visualization of Fig. 4, the terrain elevation and airspace restrictions can be displayed as these are an important factor for the flight path.

[0116] If the flight path is reprogrammed (e.g. adding a waypoint or changing the flight level), a preview is displayed as seen in Fig. 5 in the dashed line 37.

[0117] Here, the flight level is going to be changed. This results in more energy consumption. In consequence, the fraction of the energy that is consumed by the mission is getting larger. According to that, the terrain profile is stretched and the position of the waypoints is changed.

[0118] In case of a low energy situation (i.e. reaching the last 10%), the display changes as shown in Fig. 6. In this view, more airfields are displayed in the alternate layer (even closed or abandoned airfields). In contrast to the previous visualizations, an area shows the predicted flight path after the engine out (i.e. battery level = 0%). Here, the aircraft's glide path is calculated and visualized. There might be even some airfield that can be reached using the potential energy only.

[0119] Besides the vertical view, the possible range can be displayed on the moving map as well. In an idealized case without wind, airspace restrictions and high terrain this would be a simple circle around the current position of the aircraft. If these factors are present the reachable area will more look like the range shown in Fig. 7.

[0120] For information purposes, several different ranges can be displayed for example when all engines operational, one engine not operational, or all engines not operational.

List of References

[0121]

10	energy management system
12	energy calculation unit
14	first energy consumption calculation unit
16	second energy consumption calculation unit
18	airport calculation unit
20	airport determination unit
22	energy reserve determination unit
24	energy determination unit
26	bar
28	arrow
30	first side
32	second side
34	line
36	line
37	rectangular
38	dashed line
40	center point
42	area
44	second line
D1	first axis
D2	second axis

Claims

1. Method for determining airports and/or waypoints in an available range of an aircraft, comprising the steps of:

   a) Determining the available energy of the aircraft;
   b) Calculating the energy consumption for a first flight route to a first airport;
   c) Calculating the energy consumption when the aircraft heads in a second direction other than the flight direction of the first flight route;
   d) Calculating the maximum range of the aircraft in the second direction; and
   e) Determining whether a second airport and/or a waypoint is located in the second direction within the maximum range.

2. Method according to claim 1, **characterized in that** the steps c) to e) are repeated for a plurality of directions, wherein preferably the directions cover an angular range of 360°.

3. Method according to claims 1 and 2, **characterized in that** step a) includes
   a1) determining the amount of propellant stored in the aircraft and/or
   a2) determining the altitude of the aircraft and/or
   a3) determining the current speed of the aircraft.

4. Method according to any of the preceding claims, **characterized in that** step b) and/or step c) includes
   b1) determining the energy consumption depending on the altitude of the aircraft and/or
   b2) determining the energy consumption with regard to planned flight path and/or air space restrictions; and/or
   b3) determining the energy consumption based on the weather data, in particular the wind regime; and/or
   b4) determining the energy consumption based on the configurations of the aircraft and/or
   b5) determining the energy reserve and/or
   b6) determining the non-allocated energy.

5. Method according to one of the preceding claims, **characterized by** step f) that includes determining a second flight route to the second airport, wherein the second flight route includes the airport approach pattern and/or airspace restrictions.

6. Method according to claim 5, **characterized in that** step f) includes determining the energy consumption for the second flight route, wherein the determination of the energy consumption comprises
   f1) determining the energy consumption depending on the altitude of the aircraft on the second flight route and/or
   f2) determining the energy consumption based on the weather data, in particular the wind regime, for the second flight route; and/or
   f3) determining the energy consumption based on the configurations of the aircraft and/or
   f4) determining the energy reserve and/or
   f5) determining the non-allocated energy.

7. Method according to claim 6, **characterized by** step g) comprising
   g1) determining the maximum range along the second flight route based on the energy consumption of the second flight route and/or
   g2) checking whether the second airport is within the maximum range of the second flight route.

8. Method according to any of the preceding claims, **characterized in that** available energy of the aircraft is represented by a bar (28), wherein preferably the bar (28) is divided along a first axis (D1) into the energy consumed so far and/or the energy allocated for the first flight route and/or the non-allocated energy and/or the energy reserve.

9. Method according to claim 8, **characterized in that** the altitude of the aircraft is represented along a second axis (D2) of the bar (28), wherein preferably the available energy is represented over the first axis (D1).

10. Method according to claims 8 or 9, **characterized in that** at least one waypoint of the first flight route is represented on a first side (30) of the bar (28) along the first axis (D1).

11. Method according to one of the claims 8 to 10, **characterized in that** the second airport is represented on a second side (32) of the bar (28) along the first axis (D1).

12. Method according to one of the claims 8 to 11, **characterized in that** the airspace restrictions are represented in the bar (28).

13. Method according to one of the claims 8 to 12, **characterized in that** the bar (28) further includes a section along the first axis (D1) corresponding to distance which the aircraft can cover by gliding.

14. Method according to one of the preceding claims, **characterized in that** the maximum range along the second direction is represented by a first line (42) spaced apart from a center point (40).

15. Method according to claim 14, **characterized in that** the airspace restrictions are represented by areas (42) and/or the first and/or the second flight route are

represented by a second line (44), wherein preferably the second line (44) starts from the center point (42).

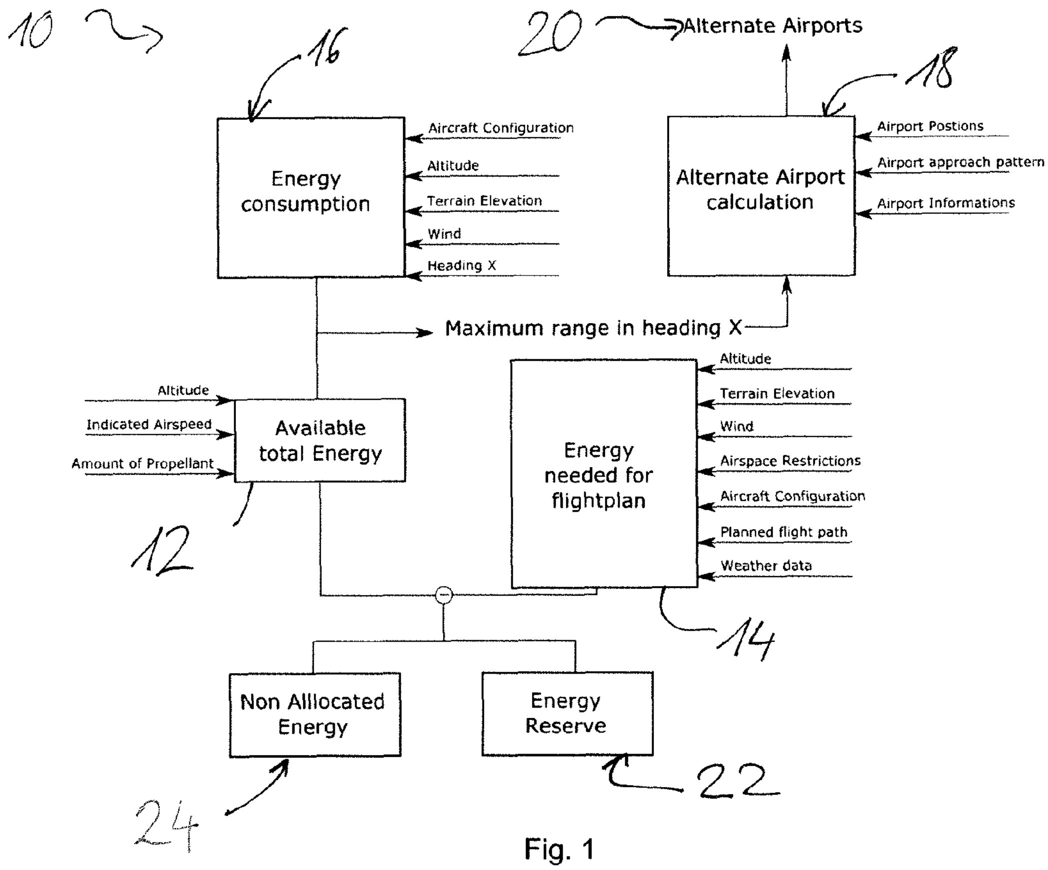
10
20
Alternate Airports
16
18
Energy consumption
Aircraft Configuration
Altitude
Terrain Elevation
Wind
Heading X
Alternate Airport calculation
Airport Postions
Airport approach pattern
Airport Informations
Maximum range in heading X
Altitude
Indicated Airspeed
Amount of Propellant
Available total Energy
Energy needed for flightplan
Altitude
Terrain Elevation
Wind
Airspace Restrictions
Aircraft Configuration
Planned flight path
Weather data
12
14
Non Alllocated Energy
Energy Reserve
24
22

Fig. 1

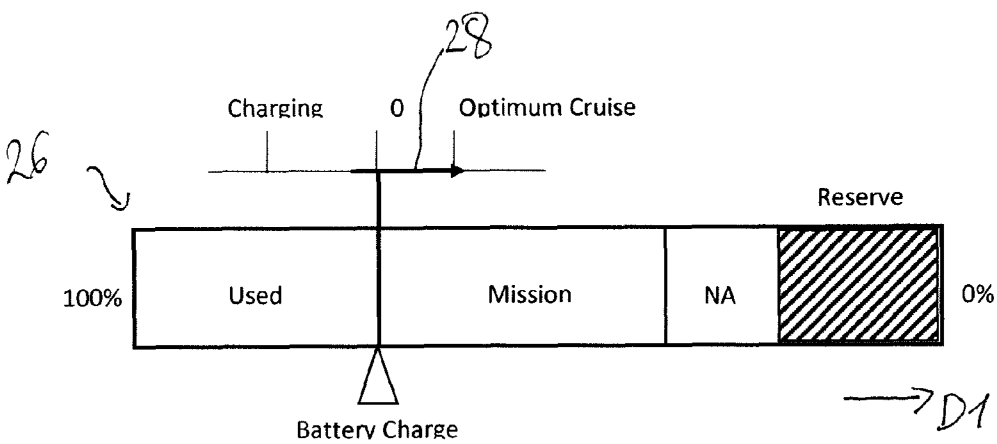
28
Charging
0
Optimum Cruise
26
Reserve
100%
Used
Mission
NA
0%
Battery Charge
D1

Fig. 2

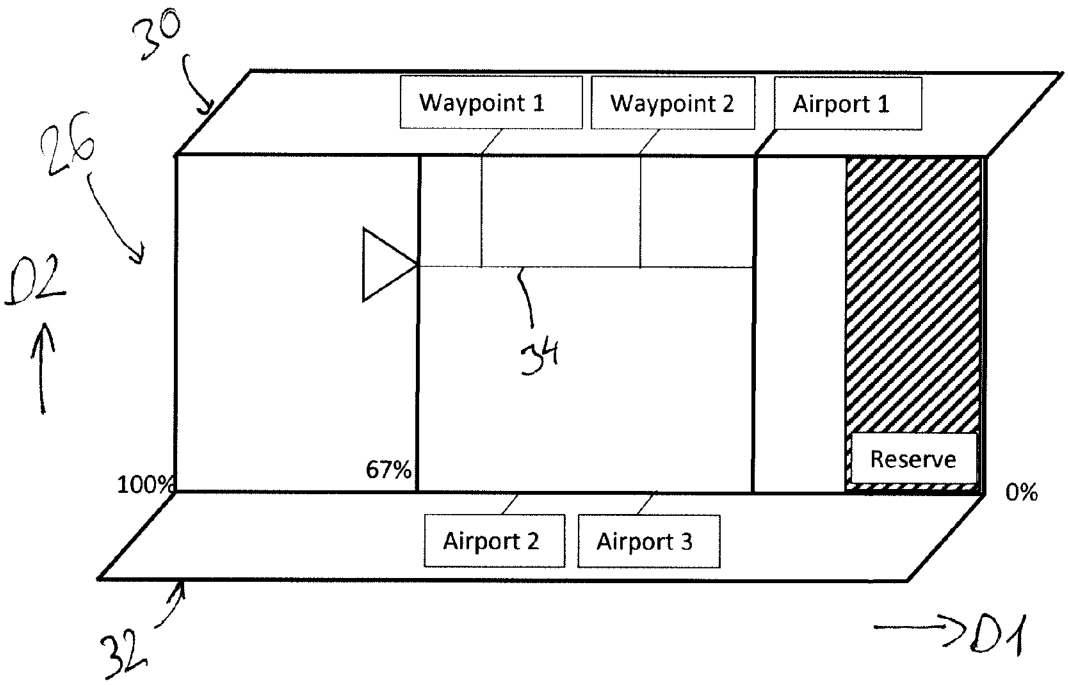
30
26
D2
Waypoint 1
Waypoint 2
Airport 1
34
Reserve
100%
67%
0%
Airport 2
Airport 3
32
D1

Fig. 3

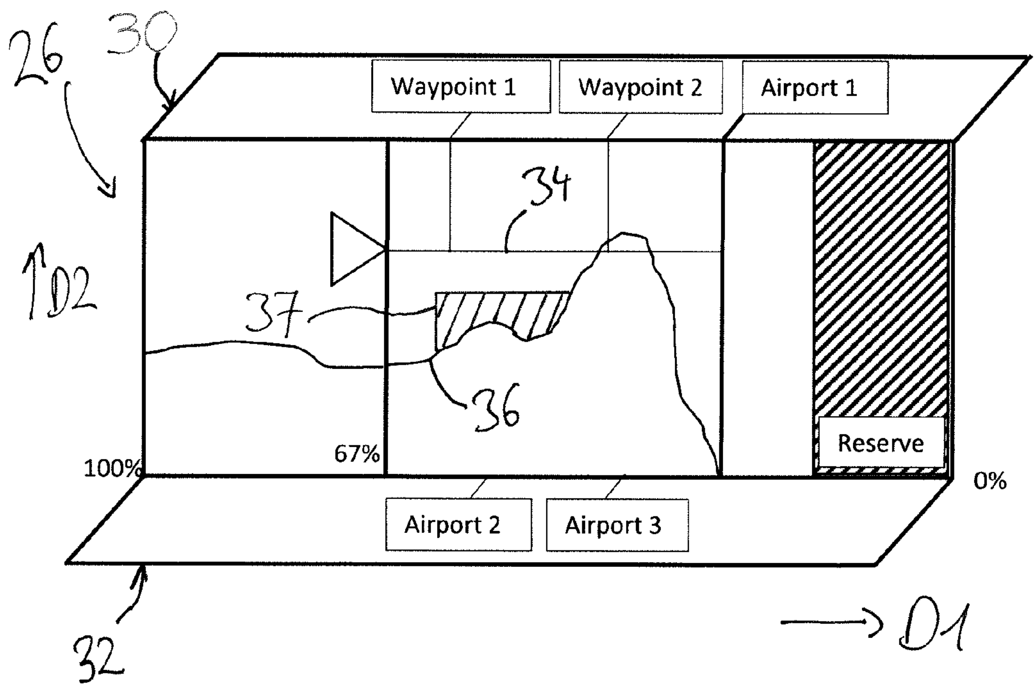
26
30
D2
Waypoint 1
Waypoint 2
Airport 1
34
37
36
Reserve
100%
67%
0%
Airport 2
Airport 3
32
D1

Fig. 4

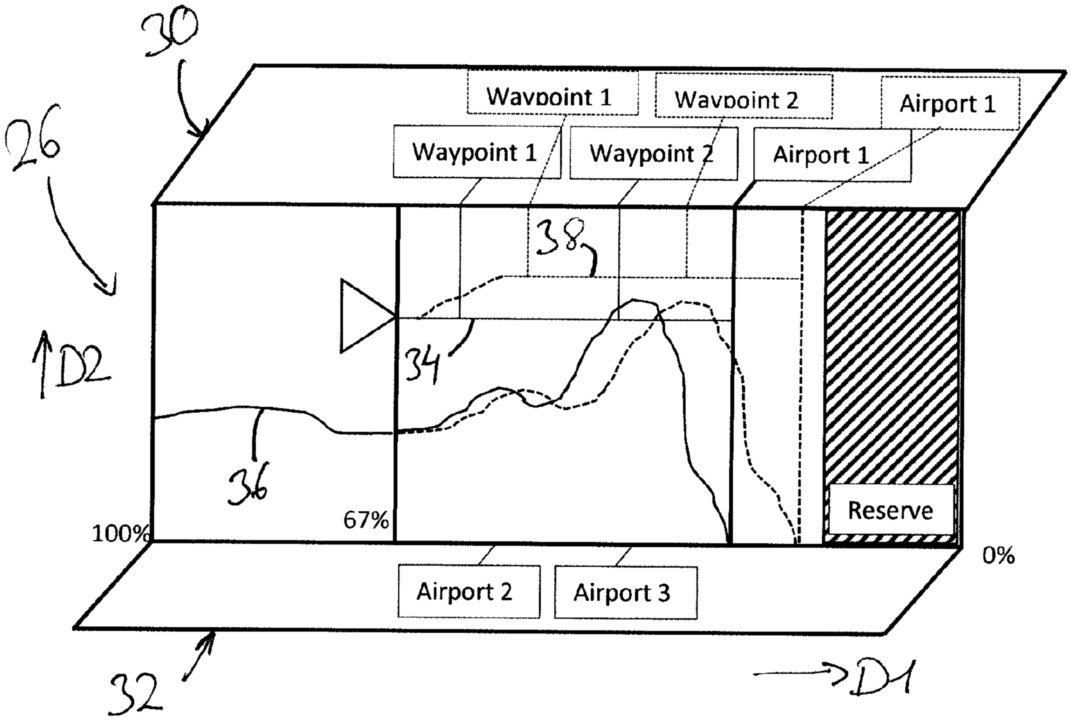
30
26
Waypoint 1
Waypoint 2
Airport 1
Waypoint 1
Waypoint 2
Airport 1
38
34
D2
36
100%
67%
Reserve
0%
Airport 2
Airport 3
32
D1

Fig. 5

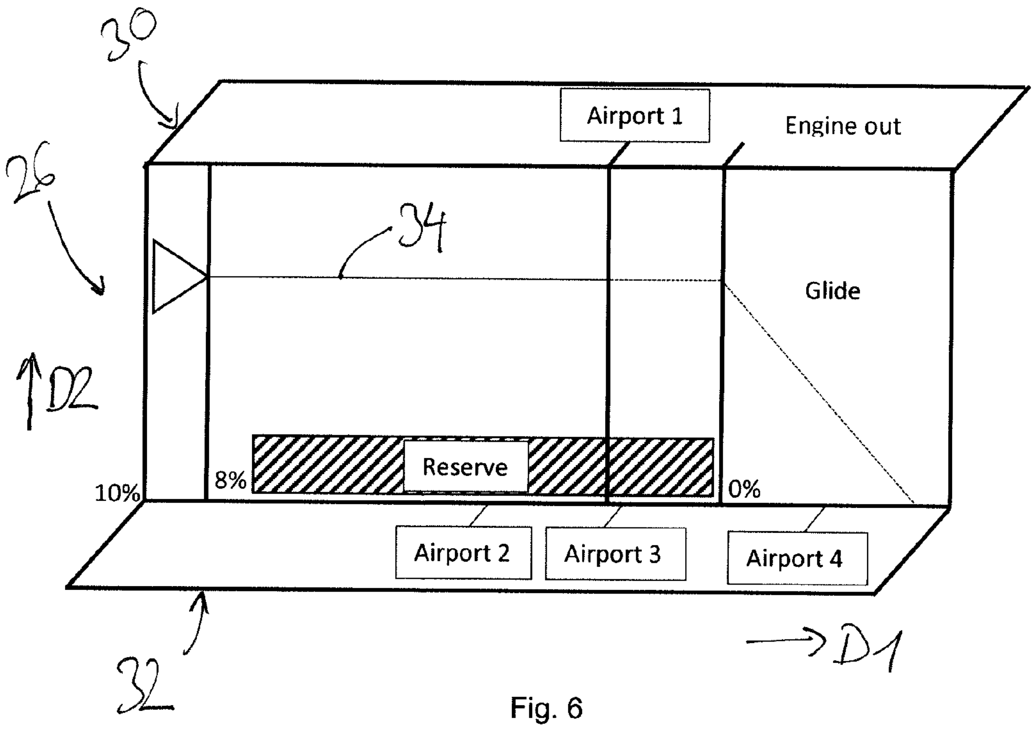
30
26
Airport 1
Engine out
34
Glide
D2
Reserve
10%
8%
0%
Airport 2
Airport 3
Airport 4
32
D1

Fig. 6

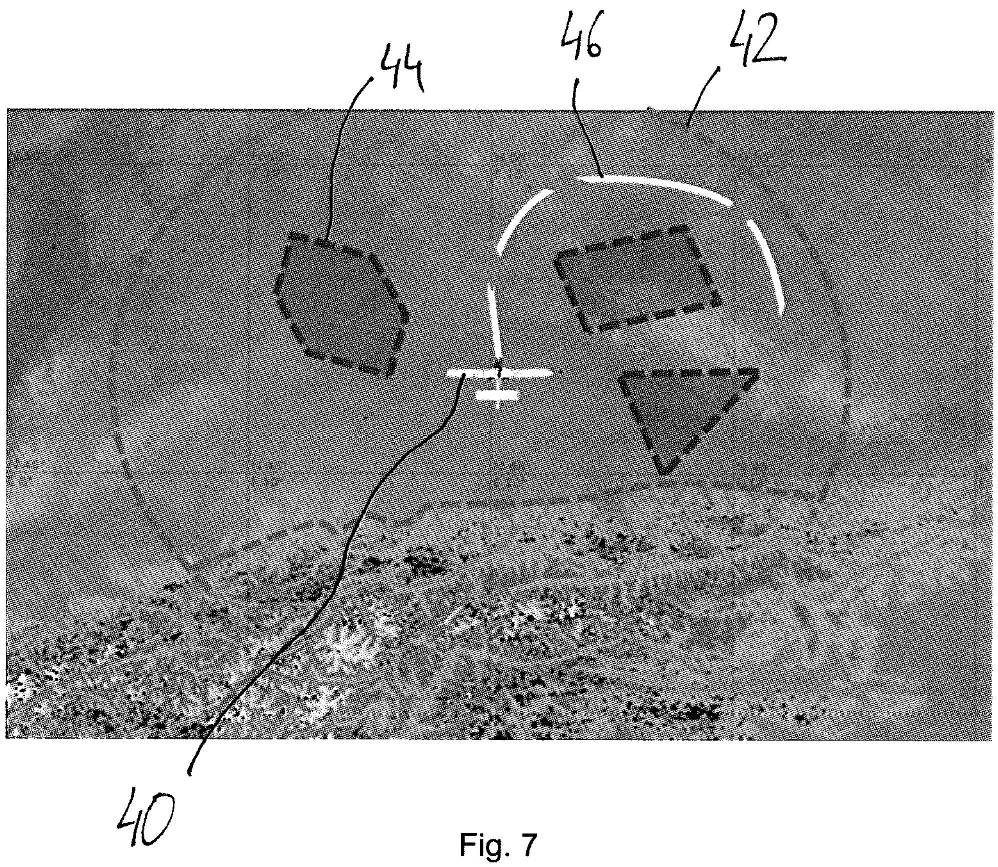

Fig. 7

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 15 17 0063

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	EP 2 790 168 A2 (AIRBUS OPERATIONS SAS [FR]) 15 October 2014 (2014-10-15) * abstract * * paragraphs [0001], [0003], [0005], [0007] - [0009], [0013], [0017] - [0021], [0026], [0029], [0032] - [0036], [0039], [0042] - [0044], [0054], [0061] - [0064] * * paragraphs [0067], [0073] - [0078]; figures 2,3-5b * -----	1-15	INV. G08G5/00
X	US 2008/300737 A1 (SACLE JEROME [FR] ET AL) 4 December 2008 (2008-12-04) * abstract * * paragraphs [0003], [0017] - [0031], [0038], [0052], [0054], [0058] - [0066], [0073], [0075] - [0085], [0093] * -----	1-7	

TECHNICAL FIELDS SEARCHED (IPC)

G08G

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	23 November 2015	Fagundes-Peters, D

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 15 17 0063

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

23-11-2015

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 2790168 A2	15-10-2014	EP 2790168 A2 US 2014309821 A1	15-10-2014 16-10-2014
US 2008300737 A1	04-12-2008	FR 2916840 A1 US 2008300737 A1	05-12-2008 04-12-2008

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Non-patent literature cited in the description

- **MERKT, JUAN R.** Flight Energy Management Training: Promoting Safety and Efficiency. *Journal of Aviation Technology and Engineering,* 2013, vol. 3 (1 **[0008]**