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Inventor(s)	Schwartz; Samantha A. et al.

System and method for taxiing operations in multi-engine aircraft

Abstract

A system and method for determining which engine of an aircraft to start first for a taxiing operation and/or for estimating a total amount of fuel needed by the aircraft for conducting the taxiing operation includes receiving or accessing historical fuel usage data for each of the first and second engines, receiving or accessing taxiway information, determining which of the first and second engines to start before the other based on optimizing one or more predetermined factors, and producing a first-to-start alert indicating which of the first and second engines is a first-to-start engine. An engine use plan may be determined, the total amount of fuel needed for executing the taxiing operation may be estimated, and a fuel-estimate indication may be produced.

Inventors: **Schwartz; Samantha A. (Castle Pines, CO), Gonzalez; Garoe (Frankfurt, DE)**

Applicant: **The Boeing Company** (Arlington, VA)

Family ID: **1000008748945**

Assignee: **THE BOEING COMPANY (Arlingotn, VA)**

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Primary Examiner: Khatib; Rami

Attorney, Agent or Firm: The Small Patent Law Group LLC

Background/Summary

INTRODUCTION

(1) This disclosure relates generally to aircraft taxiing operations, and more particularly to systems and methods for taxiing operations in multi-engine aircraft.

(2) When conducting taxiing operations with aircraft having two or more engines, it is customary practice to perform a procedure known as a reduced-engine taxiing operation (“RETO”) in which only one engine is used for taxiing on the tarmac. This is done because only one engine is required to propel the aircraft along the tarmac, such as from a terminal gate to a departing runway, and such single-engine operation saves more fuel than using more than one engine.

(3) It is also customary practice in RETO situations for the pilot to randomly select which of the two engines to start first. Without reliance on data to support this start-up decision, the pilot's choice of which engine to start first may unwittingly and detrimentally cause more fuel to be used than if the other engine were started first.

SUMMARY

(4) According to a first embodiment, a method is provided for determining which engine of an aircraft having a first engine and a second engine to start first for a taxiing operation along a taxiway at an airport. The method includes: (i) receiving or accessing historical fuel usage data for each of the first and second engines; (ii) receiving or accessing taxiway information for the taxiing operation; (iii) determining which of the first and second engines to start before the other of the first and second engines, thereby defining a first-to-start engine and a second-to-start engine, respectively, based on optimizing one or more predetermined factors; and (iv) producing a first-to-

start alert indicating which of the first and second engines is the first-to-start engine.

(5) According to a second embodiment, a system is provided for determining which engine of an aircraft having a first engine and a second engine to start first for a taxiing operation along a taxiway at an airport. The system includes a determination module and an indication module operatively connected with the determination module. The determination module has a memory configured to store an instruction set and processing circuitry configured to access the memory and execute the instruction set to: (i) receive or access historical fuel usage data for each of the first and second engines; (ii) receive or access taxiway information for the taxiing operation; (iii) determine which of the first and second engines to start before the other of the first and second engines, thereby defining a first-to-start engine and a second-to-start engine, respectively, based on optimizing one or more predetermined factors; and (iv) produce a first-to-start alert signal based on which of the first and second engines is the first-to-start engine. The indication module is configured to receive the first-to-start alert signal and produce a first-to-start alert based on the first-to-start alert signal.

(6) According to a third embodiment, a method is provided for estimating a total amount of fuel needed by an aircraft for conducting a taxiing operation along a taxiway at an airport, with the aircraft having a first engine and a second engine. The method includes: (i) receiving or accessing historical fuel usage data for each of the first and second engines; (ii) receiving or accessing taxiway information for the taxiing operation; (iii) determining which of the first and second engines to start before the other of the first and second engines, thereby defining a first-to-start engine and a second-to-start engine, respectively, based on optimizing one or more predetermined factors; (iv) determining an engine use plan for executing the taxiing operation based on the optimizing of the one or more predetermined factors, wherein the engine use plan includes starting the first-to-start engine at a first timepoint, running the first-to-start engine for a first time period after the first timepoint, starting the second-to-start engine at a second timepoint at or after an end of the first time period, and running the first-to-start and second-to-start engines for a second time period after the second timepoint; (v) estimating the total amount of fuel needed for executing the taxiing operation based on the engine use plan; and (vi) producing a fuel-estimate indication indicating the estimated total amount of fuel needed.

(7) According to a fourth embodiment, a system is provided for estimating a total amount of fuel needed by an aircraft for conducting a taxiing operation along a taxiway at an airport, with the aircraft having a first engine and a second engine. The system includes a determination module and an indication module operatively connected with the determination module. The determination module has a memory configured to store an instruction set and processing circuitry configured to access the memory and execute the instruction set to: (i) receive or access historical fuel usage data for each of the first and second engines; (ii) receive or access taxiway information for the taxiing operation; (iii) determine which of the first and second engines to start before the other of the first and second engines, thereby defining a first-to-start engine and a second-to-start engine, respectively, based on optimizing one or more predetermined factors; (iv) determine an engine use plan for executing the taxiing operation based on the optimizing of the one or more predetermined factors, wherein the engine use plan includes starting the first-to-start engine at a first timepoint, running the first-to-start engine for a first time period after the first timepoint, starting the second-to-start engine at a second timepoint at or after an end of the first time period, and running the first-to-start and second-to-start engines for a second time period after the second timepoint; (v) estimate the total amount of fuel needed for executing the taxiing operation based on the engine use plan; and (vi) produce a fuel-estimate indication signal based on the estimated total amount of fuel needed. The indication module is configured to receive the fuel-estimate indication signal and produce a fuel-estimate indication based on the fuel-estimate indication signal.

(8) In the above first embodiment, the method may include determining an engine use plan for executing the taxiing operation based on the optimizing of the one or more predetermined factors,

wherein the engine use plan includes starting the first-to-start engine at a first timepoint, running the first-to-start engine for a first time period after the first timepoint, starting the second-to-start engine at a second timepoint at or after an end of the first time period, and running the first-to-start and second-to-start engines for a second time period after the second timepoint. Similarly, in the above second embodiment, the determination module may be further configured to determine an engine use plan for executing the taxiing operation based on the optimizing of the one or more predetermined factors, wherein the engine use plan includes starting the first-to-start engine at a first timepoint, running the first-to-start engine for a first time period after the first timepoint, starting the second-to-start engine at a second timepoint at or after an end of the first time period, and running the first-to-start and second-to-start engines for a second time period after the second timepoint.

(9) In the above first embodiment, the method may include estimating a total amount of fuel needed for executing the taxiing operation based on the engine use plan, and optionally may additionally include one or both of producing a fuel-estimate indication signal based on the estimated total amount of fuel needed and producing a fuel-estimate indication indicating the estimated total amount of fuel needed. Similarly, in the above second embodiment, the determination module may be further configured to estimate a total amount of fuel needed for executing the taxiing operation based on the engine use plan, and optionally may be further configured to produce a fuel-estimate indication signal based on the estimated total amount of fuel needed, and the indication module may be configured to produce a fuel-estimate indication based on the fuel-estimate indication signal.

(10) In one or both of the above first and third embodiments, the method may include producing a first-to-start alert signal based on the determining of which of the first and second engines is the first-to-start engine. Similarly, in the above fourth embodiment, the determination module may be further configured to produce a first-to-start alert signal based on which of the first and second engines is the first-to-start engine. Additionally, in the above third embodiment, the method may include producing a first-to-start alert indicating which of the first and second engines is the first-to-start engine, and in the above fourth embodiment, the indication module may be further configured to produce a first-to-start alert based on the first-to-start alert signal.

(11) In one or both of the above first and third embodiments, the method may further include receiving or accessing historical fuel use records for one or more previous instances of the taxiing operation, wherein the historical fuel use records are for the aircraft and/or for other aircraft. Similarly, in one or both of the above second and fourth embodiments, the determination module may be further configured to receive or access historical fuel use records for one or more previous instances of the taxiing operation, wherein the historical fuel use records are for the aircraft and/or for other aircraft.

(12) In one or both of the above first and third embodiments, the method may further include producing a first-start-ready alert indicating a first OK-to-proceed condition for starting the first-to-start engine, and optionally may further include producing a second-start-ready alert indicating a second OK-to-proceed condition for starting the second-to-start engine. Additionally, in one or both of the above first and third embodiments, the method may further include producing a first-start-ready alert signal based on the engine use plan, and optionally may further include producing a second-start-ready alert signal based on the engine use plan.

(13) In one or both of the above second and fourth embodiments, the indication module may be further configured to produce a first-start-ready alert indicating a first OK-to-proceed condition for starting the first-to-start engine, and optionally may be further configured to produce a second-start-ready alert indicating a second OK-to-proceed condition for starting the second-to-start engine. Additionally, in one or both of the above second and fourth embodiments, the determination module may be further configured to produce a first-start-ready alert signal based on the engine use plan, and optionally may be further configured to produce a second-start-ready alert

signal based on the engine use plan.
(14) In one or both of the above first and third embodiments, the method may further include starting the first-to-start engine, and optionally may further include starting the second-to-start engine. Similarly, one or both of the above second and fourth embodiments, the determination module may be further configured to start the first-to-start engine, and optionally may be further configured to start the second-to-start engine.
(15) In one or more of the above embodiments, the predetermined factors may include one or more of minimizing a total amount of fuel consumed for executing the taxiing operation by the first and second engines, prioritizing whichever of the first and second engines was started first in a most previous operating cycle, prioritizing whichever of the first and second engines has a lower number of cumulative operating hours, and minimizing brake wear for the aircraft based on a number of turns present in the taxiway.
(16) In one or more of the above embodiments, the taxiway may include a plurality of taxiway features including one or more of a taxiway segment, a runway, an ascending ramp, a descending ramp, a divot and a turn, wherein each taxiway feature is associated with a respective subset of the taxiway information. Each subset of the taxiway information may include one or more of a respective set of latitude-longitude coordinates representing a location of the associated taxiway feature, a respective set of one or more vectors representing a spatial orientation of the associated taxiway feature, a respective size of the associated taxiway feature, a respective shape of the associated taxiway feature, a respective slope of the associated taxiway feature, a respective elevation of the associated taxiway feature, a respective type of the associated taxiway feature, and a respective severity rating of how the associated taxiway feature affects movement of the aircraft thereacross.
(17) In one or more of the above embodiments, the taxiway information may include one or both of historical data from previous Notice to Air Mission (NOTAM) reports and real-time data from current NOTAM reports.
(18) In one or more of the above embodiments, the first-to-start alert, the second-to-start alert, the first-start-ready alert, the second-start-ready alert and the fuel estimate indication may each comprise one or more of a visual indication on a display device, an auditory indication through an auditory device, and a vibratory indication from a vibrational device.
(19) The above features and advantages, and other features and advantages, of the present teachings are readily apparent from the following detailed description of some of the best modes and other embodiments for carrying out the present teachings, as defined in the appended claims, when taken in connection with the accompanying drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIG. **1** is a block diagram of an aircraft.
(2) FIG. **2** is a block diagram of a system according to the present disclosure.
(3) FIG. **3** is a schematic plan view of an airport at which the aircraft of FIG. **1** is located.
(4) FIG. **4** is a first timeline of start-up and run times for the first and second engines according to the present disclosure.
(5) FIG. **5** is a second timeline of taxiing operation instances according to the present disclosure.
(6) FIG. **6** is a third timeline of operating cycles for the first and second engines according to the present disclosure.
(7) FIG. **7** is a block diagram of taxiway features for a taxiway.
(8) FIGS. **8**-**9** are block diagrams illustrating how each of the first and second engines of an aircraft may be designated as a first-to-start engine or a second-to-start engine according to the present

disclosure.
(9) FIG. **10** is a block diagram of predetermined factors that may be optimized for determining which of the first and second engines is a first-to-start engine and which is a second-to-start engine according to the present disclosure.
(10) FIG. **11** is a block diagram showing components of an engine use plan according to the present disclosure.
(11) FIG. **12** is a flowchart of a method for determining which engine of an aircraft having a first engine and a second engine to start first for a taxiing operation, and of a method for estimating a total amount of fuel needed by the aircraft for conducting the taxiing operation.
DETAILED DESCRIPTION
(12) Referring now to the drawings, wherein like numerals indicate like parts in the several views, various configurations and embodiments are shown and described herein of a system **120** and method **260** for determining which engine of an aircraft **12** having a first engine **14** and a second engine **16** to start first for a taxiing operation **10** along a taxiway **104** at an airport **78**, and of a system **430** and method **440** for estimating a total amount of fuel needed **254** by the aircraft **12** for conducting the taxiing operation **10**.
(13) In the drawings and in the following specification, four different but related configurations or embodiments are presented. In the first and second embodiments, a method **260** and a system **120**, respectively, are provided for determining which engine of an aircraft **12** having a first engine **14** and a second engine **16** to start first for a taxiing operation **10** along a taxiway **104** at an airport **78**. And in the third and fourth embodiments, a method **440** and system **430**, respectively, are provided for estimating a total amount of fuel needed **254** by the aircraft **12** for conducting the taxiing operation **10**.
(14) In contrast with the abovementioned customary practices, the systems **120**, **430** and methods **260**, **400** of the present disclosure address the technical problem of knowing which of the two engines **14**, **16** is the optimum one to start first for a taxiing operation **10** and knowing the total amount of fuel needed for the taxiing operation **10**, by the technical effect of determining or calculating which of the first and second engines **14**, **16** should be a first-to-start engine **17** and which should be a second-to-start engine **19** based on specific criteria, and what impact this determination has on the total amount of fuel consumed, thereby providing significant benefits and technical advantages which are not taught or suggested by other known approaches. These benefits and technical advantages include freeing up the pilot from the effort, distraction and stress of figuring out which of the two engines **14**, **16** is the better one to start first for a taxiing operation **10** and how fuel will be utilized, thus removing a potential source of pilot error and optimizing fuel savings.
(15) FIGS. **1** and **2** show block diagrams of an aircraft **12** and a system **120** used onboard or in conjunction with the aircraft **12**, respectively, for supporting a taxiing operation **10** of the aircraft **12** at an airport **78** situated within an outside environment **82**. The taxiing operation **10** may include a reduced-engine taxiing operation (“RETO”) **18**, but may also include other types of taxiing operations **10**. The aircraft **12** may be a fixed-wing airplane belonging to an aircraft category **13**, which is a categorization, grouping or population of individual aircrafts that share common characteristics, such as manufacturer, model number, number and type of engines, etc. The aircraft **12** has at least a first engine **14** and a second engine **16**, with the aircraft **12** being capable of performing the taxiing operation **10**. The second engine **16** (and optionally the first engine **14** as well) belongs to an engine category **20**, which is a categorization, grouping or population of individual engines sharing common characteristics, such as manufacturer, model number, engine displacement, etc.
(16) It may be noted that while individual engines within an engine category **20** will have certain characteristics that are the same for all the engines in that category **20**, there may be some characteristics which vary from one individual engine to another, such as age, number of service

hours and maintenance/repair history. Similarly, while individual aircrafts within an aircraft category **12** will have certain characteristics that are the same for all the aircrafts in that category **12**, there may be some characteristics which vary from one individual aircraft to another, such as age, number of service hours, maintenance/repair history and the like.

(17) The aircraft **12** includes a cockpit **22** containing a seat **24** in which a pilot **26** may sit. The cockpit **22** may also include various control devices **28** and display devices **30** with which the pilot **26** may interact. For example, the control devices **28** may include a steering yoke **32**, a throttle lever **34**, a control stick **36** (which may include or be called a control lever and/or a joystick) and one or more control pedals **38** (such as for controlling the rudder and/or brakes). The display devices **30** may include a heads-up display ("HUD") **40** which the pilot **26** may wear in the form of goggles, glasses, a visor, etc., as well as one or more display screens **42** mounted within the cockpit **22**. The HUD **40** and display screens **42** may be wired or wireless. Each of the display devices **30** may be configured for displaying one or more visual indications **43** thereon. These visual indications **43** may be in the form of text, icons, symbols or the like, which may be shown in special renderings such as special colors, large text and/or in a flashing, pulsing, moving or rotating format in order to attract a pilot's attention.

(18) The cockpit **22** may additionally include one or more auditory devices **44** which are configured to emit sound(s) for the benefit and/or the attention of the pilot **26**. For example, the auditory devices **44** may include a speaker/loudspeaker **46** mounted within the cockpit **22**, and/or a speaker **48** mounted in a headset **50** which the pilot **26** may wear. (As used here, the "headset" may include an in-the-ear, on-the-ear or around-the-ear earset, a set of headphones and a set of one or more earplugs/earphones.) The speakers **46**, **48** and headset **50** may be wired or wireless. Each of the auditory devices **44** may be configured for emitting one or more auditory indications **51** therefrom. These auditory indications **51** may be sounds in the form of beeps, chirps, speech or the like, which may be emitted in special renderings such as special sounds, increased volume and/or in a pulsing or undulating auditory format in order to attract a pilot's attention.

(19) The cockpit **22** may further include one or more vibrational devices **52** which are configured to emit vibrations, buzzes or the like for the benefit and/or the attention of the pilot **26**. For example, the vibrational device **52** may be a piezo-electric element which converts an electrical signal into mechanical vibration. These vibrational devices **52** may be attached to or embedded within one or more of the steering yoke **32**, the throttle lever **34**, a control lever/control stick/joystick **36**, the one or more control pedals **38**, a footrest **54** (including a footrest area in the footwell of the cockpit **22**), the pilot's seat **24**, and any other suitable location or device **25** within the cockpit **22**. In addition to producing vibrations which the pilot **26** may feel, the vibrational device **52** may optionally also be capable of producing one or more sounds which the pilot **26** is capable of hearing. Each of the vibrational devices **52** may be configured for emitting one or more vibratory indications **55** therefrom. These vibratory indications **55** may be vibrations, pulses, buzzes or the like, which may be emitted in special renderings such as special sequences or patterns, or pulses that are rising, falling, undulating, abrupt, etc., in order to attract a pilot's attention.

(20) Each of these display devices **30**, auditory devices **44** and vibratory devices **52** may be used to provide visual indications **43**, auditory indications **51** and vibrational indications **55**, respectively, so as to provide an alert **142** to the pilot **26** regarding which of the first and second engines **14**, **16** to start first and/or what the total amount of fuel needed **254** is for conducting the taxiing operation **10**, as described in more detail below.

(21) The aircraft **12** may include one or more internal sensors **56** located within the interior **58** of the aircraft **12**, one or more external sensors **60** located on the exterior **62** of the aircraft **12**, one or more accessing/processing circuits **64** within the interior **62** of the aircraft **12** which are configured to access or retrieve stored information **66** from a storage medium **68** located within the interior **58** of the aircraft **12**, and/or one or more transceivers **70** which in whole or in part may be located

within the interior **58** of the aircraft **12** and/or on the exterior **62** of the aircraft **12**. These sensors **56**, **60**, circuits **64** and transceivers **70** may be controlled by one or more controllers **71** for handling the storage, retrieval and flow of signals and information among these and other devices aboard the aircraft **12**. Note that as used herein, the “interior” **58** of the aircraft **12** includes locations that are within the cockpit **22**, within the passenger/cargo areas, within the engines **14**, **16** and anywhere within the entirety of the aircraft **12** and which is not directly exposed to the outer atmosphere outside the aircraft **12**. Similarly, the “exterior” **62** of the aircraft **12** includes all other locations that are not within the interior **58**, such as any locations on or outside of the outer skin or outer boundary surfaces of the aircraft **12**, and any locations that are directly exposed to the outer atmosphere outside the aircraft **12**. Further, note that while FIG. **1** shows the accessing/processing circuit **64**, the stored information **66**, the storage medium **68**, a portion of the transceiver **70** and the controller **71** as being located within the interior **58** of the aircraft **12** but outside the cockpit **22**, this is merely for illustration purposes, as these elements may also be located within the cockpit **22**.

(22) The internal sensor(s) **56**, the external sensor(s) **60**, the accessing/processing circuit(s) **64** and the transceiver(s) **70** may cooperate together and be configured to sense or access various phenomena, characteristics, data and/or signals which convey various types of information. As illustrated at the lower-right of FIG. **2**, and with reference to the airport **78** illustrated in FIG. **3**, the aforementioned information may include engine-related information **72** relating to the second engine **16** (and/or to the engine category **20** to which the second engine **16** belongs), aircraft-related information **74** relating to the aircraft **12** (which may optionally include or exclude engine-related information **72**), airport-related information **76** relating to the airport **78** at which the aircraft **12** is located, and/or environment-related information **80** relating to the outside environment **82** in which the airport **78** is located. For example, one or more internal sensors **56** and/or one or more external sensors **60** may be operatively associated with each engine **14**, **16** in order to sense various engine-related information **72**, such as the engine temperature, oil temperature and oil pressure for each engine **14**, **16**. Environment-related information **80** such as the outside air temperature, barometric pressure, humidity, dew point, wind speed, wind direction, visibility and the like may be sensed by one or more external sensors **60** and/or such information may be received onboard the aircraft **12** by one or more transceivers **70** (e.g., radios) from an external database, service or source **84**. Such external databases, services or sources **84** may be commercial information sources that are encrypted, password-protected and subscription-based, or they may be information sources that are publicly available and free-of-charge. These external databases, services or sources **84** may be located on the premises of the airport **78**, or they may be located some distance away from the premises of the airport **78**.

(23) As illustrated by the large dashed rounded rectangle at the lower-right of FIG. **2**, the set of data and information making up the engine-related information **72**, the aircraft-related information **74**, the airport-related information **76** and the environment-related information **80** may include one or both of historical information **86** (which has been accumulated over time before a current moment) and real-time information **88** (which is sensed or accessed at the current moment in real time). Historical information **86** may be stored in the cloud, and may be accessible by the aircraft **12** from an external database, service or source **84** via a transceiver **70**. Alternatively, the historical information **86** may be stored in the storage media **68** among the stored information **66**, which may be accessible via the accessing/processing circuit **64**. Additionally, historical information **86** may be received from an external database, service or source **84** by the transceiver **70** and stored as stored information **66** in the storage medium **68** with the aid of the controller **71**.

(24) As illustrated by the small dashed rounded rectangle at the lower-right of FIG. **2**, the engine-related information **72** and the aircraft-related information **74** may each include one or both of instantial information **90**, relating to the second engine **16** itself or to the aircraft **12** itself, and categorical information **92**, relating to the engine category **20** to which the second engine **16** belongs or to the aircraft category **13** to which the aircraft **12** belongs. In other words, the engine-

related information **72** may include instantial information **90** relating to the second engine **16** itself, and/or categorical information **92** relating to the engine category **20** to which the second engine **16** belongs. Similarly, the aircraft-related information **74** may include instantial information **90** relating to the individual aircraft **12** itself, and/or categorical information **92** relating to the aircraft category **13** to which the aircraft **12** belongs. It may be noted that while categorical information **92** definitionally relates to an aircraft category **13** or to an engine category **20**, such information **92** may be viewed as also indirectly relating to an individual aircraft **12** or to an individual second engine **16**, since the individual aircraft **12** or individual second engine **16** belongs to the respective aircraft category **13** or engine category **20**. (Further, note that the descriptions above relating to the second engine **16** may likewise apply to the first engine **14** as well.)

(25) The internal sensors **56**, external sensors **60**, accessing/processing circuits **64** and transceivers **70** may be utilized (optionally with the aid of the controller **71**) to sense, receive or access the various types of historical information **86**, real-time information **88**, instantial information **90** and categorical information **92** mentioned above.

(26) As illustrated in the block diagram of FIG. **2**, the system **120** includes a determination module **122** and an indication module **124** operatively connected with the determination module **122**. The determination module **122** includes a memory **126** configured to store an instruction set **128**, and processing circuitry **130** configured to access the memory **126** and to retrieve and execute the instruction set **128**. (The controller **71** illustrated in FIG. **1** (including one or more of the accessing/processing circuit **64**, the storage medium **68** and the stored info **66**) may include or comprise the determination module **122** illustrated in FIG. **2** (including one or more of the processing circuitry **130**, the memory **126** and the instruction set **128**), and vice versa.) The execution of the instruction set **128** by the processing circuitry **130**, and/or the operation of the determination module **122**, are configured so as to be effective to determine which of the first and second engines **14**, **16** to start before the other of the first and second engines **14**, **16**, thereby defining a first-to-start engine **17** and a second-to-start engine **19**, respectively (hereinafter a "determination" **123**).

(27) In order to make the determination **123** of which of the engines **14**, **16** should be the first- and second-to-start engines **17**, **19**, the determination module/instruction set **122**, **128** may be configured to receive or access historical fuel usage data **158** for each of the first and second engines **14**, **16** and taxiway information **160** for the taxiing operation **10**. Optionally, the determination module/instruction set **122**, **128** may also be configured to receive or access historical fuel use records **159** for one or more previous instances **202** of the taxiing operation **10**. Additionally, the determination module/instruction set **122**, **128** may also be configured to determine which of the first and second engines **14**, **16** should be started before the other, thereby defining the first-to-start (i.e., first-to-be-started) engine **17** and the second-to-start (i.e., second-to-be-started) engine **19**, respectively, based on optimizing one or more predetermined factors **212**. The determination module/instruction set **122**, **128** may also be configured to produce an alert signal **136** based on the determination **123**.

(28) The historical fuel usage data **158** includes data pertaining to fuel usage by each engine **14**, **16** during previous taxiing operations **10** (and optionally during other operations as well), such as total amount of fuel consumed during an operation, flow rates of fuel during the operation, duration of the operation, average fuel flow rate for an operation, fuel use efficiency for an operation, etc.

(29) The historical fuel use records **159** include records pertaining to fuel use during previous instances of the current, planned or contemplated taxiing operation **10** (and optionally during other taxiing operations **10** as well). These records **159** may pertain to the overall taxiing operation **10**, and thus may include total measurements for both engines **14**, **16** combined together. For example, historical fuel use records **159** may include the combined amount of fuel consumed during an operation, combined flow rates of fuel during the operation, duration of the operation, combined average fuel flow rate for an operation, combined fuel use efficiency for an operation, etc. Note

that since the historical fuel use records **159** combines data/measurements from both engines **14**, **16** over the course of a taxiing operation **10**, the records **159** may include data/measurements coming from only one engine or the other during some portions of the taxiing operation **10**. For example, as illustrated in the timeline of FIG. **4**, at the beginning of a taxiing operation **10**, a first-to-start engine **17** may run during a first time period **194** from a first timepoint T.sub.1 to a second timepoint T.sub.2, and a second-to-start engine **19** may begin running at the second timepoint T.sub.2 until a third timepoint T.sub.3, which defines a second time period **196** during which both engines **17**, **19** are running for the taxiing operation **10**. Thus, fuel would only be consumed by one engine (i.e., the first-to-start engine **17**) during the first time period **194**, whereas fuel would be consumed at a much higher rate during the second time period **196** when both engines **17**, **19** would be running.
(30) The taxiway information **160** is illustrated in the block diagram of FIG. **7**, with reference to the schematic diagram of the airport **78** and taxiway features **105** shown in FIG. **3**.
(31) In FIG. **3**, the instant aircraft **12** and other aircraft **15** are shown at an airport **78**. The airport **78** is located within a surrounding environment **82**, which may have a geographical location with local weather conditions. For example, the environment **82** may have a municipal, corporate or private address with latitude and longitude coordinates and an elevation above sea level, with the environment **82** also having local readings of air temperature, barometric pressure, relative humidity, dew point, wind speed, wind direction, visibility and the like.
(32) The airport **78** may operate and be governed by a set of standard operating procedures (“SOPs”) **94**, which may be a combination of rules, restrictions, permissions and guidelines promulgated by federal, state and/or local agencies for the safe operation of airport facilities. The airport **78** may include one or more terminals **96** each having one or more respective gates **98**. The airport **78** additionally includes one or more arriving runways **100** and one or more departing runways **102**, with a network of taxiways **104** directly or indirectly connecting each gate **98** with at least one arriving runway **100** and at least one departing runway **102**. The network of taxiways **104** may include one or more taxiway segments **106**, one or more ascending ramps or segments **108** (which rise in elevation), one or more descending ramps or segments **110** (which fall in elevation), one or more turns **112** and one or more divots **114** in the runways **100**, **102** and/or in the taxiways **104**. Note that while an ascending ramp or segment **108** is shown at the junction of one taxiway segment **106** and the arriving runway **100**, and a descending ramp or segment **110** is shown at the junction of another taxiway segment **106** and the departing runway **102**, such ramps **108**, **110** may occur at other locations as well. Additionally, the runways **100**, **102** and taxiways **104** may have various combinations of banking and/or crowning on their respective top surfaces.
(33) In FIG. **7**, a taxiway **104** is shown as comprising one or more taxiway features **105**, such as one or more taxiway segments **106**, one or more ascending ramps/segments **108**, one or more descending ramps/segments **110**, one or more turns **112**, one or more divots **114**, and one or more other taxiway features **116**. Each of these taxiway features **105**—i.e., **106**, **108**, **110**, **112**, **114** and **116**—may be associated with a respective subset **162** of the taxiway information **160**—i.e., **106′**, **108′**, **110′**, **112′**, **114′** and **116′**, respectively. The taxiway information **160**, illustrated by the dashed rounded rectangle, is a collection of information about various characteristics of the taxiway features **105**, such as: (i) the set of latitude-longitude coordinates **164** representing the location **166** of a taxiway feature **105**, (ii) the set of one or more vectors **168** representing or characterizing a spatial orientation or directionality **170** of a taxiway feature **105**, (iii) the size **172** of a taxiway feature **105**, (iv) the shape **174** of a taxiway feature **105**, (v) the slope **176** of a taxiway feature **105**, (vi) the elevation **178** of a taxiway feature **105**, (vii) the type **180** of a taxiway feature **105**, and (viii) the severity or impact rating **182** of how a taxiway feature **105** is likely to affect movement of the aircraft **12** across the taxiway feature **105**.
(34) Each subset **162** of the taxiway information **160** may include one or more of the abovementioned characteristics. For example, if a given taxiway **104** has four taxiway segments **106**, then the subset **106′** associated with the four taxiway segments **106** may include four sets of

latitude-longitude coordinates **164** for the respective locations **166** of the four segments **106**, four set of vectors **168** representing or characterizing the respective spatial orientation or directionality **170** of the four segments, a respective size **172** and shape **174** for each of the four segments, etc.
(35) FIGS. **4-6** show various timelines for running the first and second engines **14**, **16** during taxiing operations **10** at an airport **78** according to the present disclosure. More specifically, FIG. **4** shows a first timeline I of start-up and run times for the first and second engines **14**, **16**, FIG. **5** shows a second timeline II of various instances **198** of the taxiing operation **10**, and FIG. **6** shows a third timeline III of various operating cycles **204** for the first and second engines **14**, **16**. In some cases, at least some of the events and/or timepoints illustrated in FIGS. **4-6** may coincide and/or align with each other, but in other cases few or none of the events and timepoints may coincide and/or align with each other.
(36) In FIG. **4**, a first time period **194** extends from a first timepoint T.sub.1 to a second timepoint T.sub.2, and a second time period **196** extends from the second timepoint T.sub.2 to a third timepoint T.sub.3. The first time period **194** represents a first OK-to-proceed condition **195** for starting the first-to-start engine **17**, and the second time period **196** represents a second OK-to-proceed condition **197** for starting the second-to-start engine **19**.
(37) In FIG. **5**, several individual instances or occurrences **198** of the taxiing operation **10** are represented by the dots shown at the fourth, fifth, sixth, seventh, eighth and ninth timepoints T.sub.4, T.sub.5, T.sub.6, T.sub.7, T.sub.8, T.sub.9. A current instance **200** is shown occurring at the ninth timepoint T.sub.9, with multiple previous instances **202** shown occurring at the fourth through eighth timepoints T.sub.1-T.sub.8. Note that each instance **198** in FIG. **5** may include respective first and second time periods **194**, **196** as illustrated in FIG. **4**; thus, the second timeline II of FIG. **5** shows a longer span of time than does the first timeline I of FIG. **4**.
(38) In FIG. **6**, several individual operating cycles **204** of the engines **14**, **16** are represented by the squares shown at the tenth, eleventh, twelfth, thirteenth, fourteenth, fifteenth and sixteenth timepoints T.sub.10, T.sub.11, T.sub.12, T.sub.13, T.sub.14, T.sub.15, T.sub.16. Each operating cycle **204** may include a taxiing operation **10** as well as other operations of the engines **14**, **16**. A current operating cycle **206** is shown occurring at the sixteenth timepoint T.sub.16, with multiple previous operating cycles **208** shown occurring at the tenth through fifteenth timepoints T.sub.10-T.sub.15, including a most previous operating cycle **210** immediately prior to the current operating cycle **206**.
(39) FIGS. **8-9** show block diagrams illustrating how each of the first and second engines **14**, **16** may be designated as a first-to-start engine **17** or a second-to-start engine **19**. For example, in FIG. **8**, the determination **123** has resulted in the first engine **14** being recommended to be the first-to-start engine **17** and the second engine **16** being the second-to-start engine **19**, as indicated by the solid lines connecting block **14** to block **17** and block **16** to block **19**. On the other hand, in FIG. **9**, the determination **123** has resulted in the second engine **16** being recommended to be the first-to-start engine **17** and the first engine **14** being the second-to-start engine **19**, as indicated by the solid lines connecting block **16** to block **17** and block **14** to block **19**. As noted above, the determination **123** as to whether a given engine **14**, **16** should be the first-to-start engine **14** is determined by optimizing one or more of the predetermined factors **212**. Each engine **14**, **16** may also have or be associated with its own respective historical fuel usage data **14′**, **16′** (both of which may be grouped together as parts of the collective group of historical fuel usage data **158**) and its own respective number of cumulative operating hours **14″**, **16″** (both of which may be grouped together as parts of the collective number of cumulative operating hours **230**).
(40) FIG. **10** shows a block diagram of the predetermined factors **212** utilized by the determination module **122** to make the determination **123**. These factors **212** may include one or more of: (i) at block **222**, minimizing a total amount of fuel consumed **224** for executing the taxiing operation **10** by the first and second engines **14**, **16**; (ii) at block **226**, prioritizing whichever of the first and second engines **14**, **16** was started first in a most previous operating cycle **210**; (iii) at block **228**,

prioritizing whichever of the first and second engines **14**, **16** has a lower number of cumulative operating hours **230**; and (iv) at block **232**, minimizing brake wear **234** for the aircraft **12** based on a number of turns **112** present in the taxiway **104**.

(41) As used herein, the determination **123** being based on "optimizing" one or more of the predetermined factors **212** means that the determination **123** or decision as to which of the engines **14**, **16** should be identified as the first-to-start engine **17** is based on accomplishing the one or more predetermined factors **212** to the highest practical degree.

(42) For example, if historical fuel use data **14′** for the first engine **14** and historical fuel use data **16′** for the second engine **16** indicate that during previous instances **202** of the taxiing operation **10** the first engine **14** consumed fuel at a higher rate than did the second engine **16**, then optimizing the first of the predetermined factors **212** (represented by block **222**) would result in identifying the second engine **16** to be the first-to-start engine **17** (to run during both the first and second time periods **194**, **196**) and the first engine **14** to be the second-to-start engine **19** (to run during only the second time period **196**), because this combination would minimize the total amount of fuel consumed **224** for the taxiing operation **10**.

(43) As another example, if in the most previous operating cycle **210** the first engine **14** was started before the second engine **16**, then according to the second of the predetermined factors **212** (represented by block **226**), during the current operating cycle **206** the second engine **16** would be prioritized over the first engine **14**; that is, the second engine **14** would be identified as the first-to-start engine **17** for the current operating cycle **206** of the taxiing operation **10**.

(44) As yet another example, if the cumulative operating hours **14″** for the first engine **14** are lower than the cumulative operating hours **16″** for the second engine **16**, then according to the third of the predetermined factors **212** (represented by block **228**), the first engine **14** should be the first-to-start engine **17**, in order to balance out the engine wear as between the two engines **14**, **16**.

(45) As yet a further example, if the taxiway **104** has more left turns that right turns (or vice versa) along the path that the aircraft **12** will take from the gate **98** to the departing runway **102**, then according to the fourth of the predetermined factors **212** (represented by block **232**), one of the engines **14**, **16** would be prioritized over the other and selected to be the first-to-start engine **17** in order to minimize the overall brake wear **234** caused by the turns **112** along the taxiway **104**.

(46) In cases where more than one of the predetermined factors **212** are being considered and optimized, there may be situations in which two or more of the factors **212** conflict or compete with each other. For example, two of the factors **212** may indicate that the first engine **14** should be the first-to-start engine **17**, and the other two factors **212** indicate that the second engine **16** should be the first-to-start engine **17**. In such cases, a hierarchical, procedural, weighted or arbitrational scheme may be used to arbitrate or decide between or among the factors **212** in order to select which engine **14**, **16** should be the first one to be started.

(47) Optionally, the determination **123** may also utilize or be based on one or more of engine-related information **72**, aircraft-related information **74**, airport-related information **76**, and environment-related information **80**. For example, the instruction set **128** may include one or more algorithms that utilize the engine-related information **72**, the aircraft-related information **74**, the airport-related information **76**, and/or the environment-related information **80** as inputs for the one or more algorithms.

(48) The determination module **122** may receive or access the historical fuel usage data **158**, historical fuel use records **159** and taxiway information **160** via the internal sensors **56**, the external sensors **60**, the accessing/processing circuits **64** and/or the transceivers **70**. (For example, some portions of this data **158**, records **159** and information **160** may be sensed by the internal or external sensors **56**, **60**, and other portions may be accessed via the accessing/processing circuits **64** (e.g., from the stored information **66** on the storage medium **68**) or via the transceivers **70** (e.g., from an external database, service or source **84**). Additionally, the indication module **124** is configured to receive the alert signal **136** and produce an alert **142** based on the alert signal **136**.

The alert signal **136** may be an analog signal, a digital signal or a combined analog and digital signal.
(49) When the alert signal **136** is produced by the determination module **122** and is received by the indication module **124**, the indication module **124** sends one or more other signals (which are different from the alert signal **136**) to one or more display device **30**, one or more auditory device **44** and/or one or more vibrational device **52**, so as to produce one or more visual indications **43**, one or more auditory indication **51** and/or one or more vibratory indications **55**, respectively. These various indications **43**, **51**, **55** provide information to the pilot **26** regarding which engine **14**, **16** is the first-to-start engine **17** and which is the second-to-start engine **19**, when to start each engine **17**, **19**, etc.
(50) The alert **142** may include or take the form of a visual indication **43** on a display device **30**, an auditory indication **51** through an auditory device **44**, and/or a vibratory indication **55** from a vibrational device **52**. The alert **142** may also include or take the form of an indicator **144** of which engine **14**, **16** to start first (i.e., which engine **14**, **16** has been determined to be a first-to-start engine **17** and/or which is a second-to-start engine **19**), a countdown **146** (indicating when to start the first-to-start engine **17** and/or the second-to-start engine **19**), and/or a prompt **148** to start the first-to-start engine **17** and/or the second-to-start engine **19**. Each of the visual, auditory and vibratory indications **43**, **51**, **55** may be provided in the form of a respective indicator **144**, a respective countdown **146** or a respective prompt **148**. It may be noted that the alert **142** may be presented in multiple forms or formats and at more than one singular time.
(51) For example, after the determination **123** has been made by the determination module **122** as to which engine **14**, **16** should be the first-to-start engine **17**, the determination module **122** produces an alert signal **136** that is indicative of the determination **123**. This alert signal **136** is received by the indication module **124**, and the indication module **124** then produces an alert **142** which, like the alert signal **136**, is indicative of the determination **123** made by the determination module **122**. The alert **142** may optionally include a continuation of the alert **142** until the pilot **26** acknowledges the alert **142**, such as by pressing a designated button or by starting the first-to-start engine **17**.
(52) Optionally, the determination module **122** may be configured to produce two or more alert signals **132**, and the indication module **124** may be configured to receive the two or more alert signals **132** from the determination module **122** and to produce two or more alerts **142** which correspond to the two or more alert signals **136**. Two or more alerts signals **136** and their corresponding alerts **142** may be utilized to indicate or signal two or more conditions or actions. In one example, alerts **142** may be presented at two different timepoints: (i) at a first timepoint T.sub.1, one alert **142** may be presented as both an indicator **144** as to which engine **14**, **16** should be the first-to-start engine **17** and as a prompt **148** to proceed with starting the first-to-start engine **17**, and simultaneously another alert **124** may be presented as a countdown **146** until it is time to start the second-to-start engine **19**; and (ii) at a second timepoint T.sub.2 at the end of the countdown **146**, another alert **142** may be presented as a prompt **148** to proceed with starting the second-to-start engine **19**.
(53) For instance, at the first timepoint T.sub.1, a combination of three different forms of the alerts **142** may be simultaneously triggered: (i) an auditory indication **51** in the form of three short beeps may be emitted from an auditory device **44** (e.g., in a cockpit loudspeaker **46** and in a headset speaker **48**); (ii) a flashing series of numbers showing a countdown **146** may be displayed as a visual indication **43** on a display device **30** (e.g., in the HUD **40** and on one or more display screens **42**); and (iii) a vibratory indication **55** in the form of three short vibrational pulses may be emitted from one or more vibrational devices **52** (e.g., by piezo-electric elements embedded in the steering yoke **32**, the throttle lever **34** and the control stick **36**). Then, at the second timepoint T.sub.2 (i.e., at the end of the countdown **146**, when it is time to commence start-up of the second-to-start engine **19**), another combination of three different forms of the alert **142** may be triggered: (iv) an auditory

indication **51** in the form of one long beep may be emitted from an auditory device **44** (e.g., in a cockpit loudspeaker **46** and in a headset speaker **48**); (v) the flashing series of numbers showing the countdown **146** may disappear and be replaced by a flashing icon displayed as a visual indication **43** on a display device **30** (e.g., in the HUD **40** and on one or more display screens **42**); and (vi) a vibratory indication **55** in the form of one long vibrational pulse may be emitted from one or more vibrational devices **52** (e.g., by piezo-electric elements embedded in the steering yoke **32**, the throttle lever **34** and the control stick **36**). In this example, at the first timepoint T.sub.1, the timing and cadence of the three short beeps may match the timing and cadence of the three short vibrational pulses, and at the second timepoint T.sub.2, the timing and duration of the one long beep may match the timing and duration of the one long vibrational pulse. Other combinations of visual, auditory and vibratory indications **43**, **51**, **55** and indicators **144**, countdowns **146** and prompts **148** utilizing the various control devices **28**, display devices **30**, auditory devices **44** and vibrational devices **52** are also possible.

(54) FIG. **11** shows a block diagram of an engine use plan **236** for executing the taxiing operation **10** based on the optimizing of the one or more predetermined factors **212**. With reference to the first timeline I of FIG. **4**, the engine use plan **236** may include the sequence of steps or actions of: (i) starting the first-to-start engine **17** at a first timepoint T.sub.1, (ii) running the first-to-start engine **17** for a first time period **194** after the first timepoint T.sub.1, (iii) starting the second-to-start engine **19** at a second timepoint T.sub.2 at or after an end of the first time period T.sub.1, and (iv) running the first-to-start and second-to-start engines **17**, **19** for a second time period **196** after the second timepoint T.sub.2.

(55) FIG. **12** is a flowchart for determining which engine **14**, **16** to start first for a taxiing operation **10** according to the method **260** and system **120** of the abovementioned first and second embodiments, respectively. FIG. **12** is also a flowchart for estimating a total amount of fuel needed **254** by the aircraft **12** for conducting the taxiing operation **10** according to the method **440** and system **430** of the abovementioned third and fourth embodiments, respectively. It should be noted that while FIG. **12** shows steps from block **270** to block **420**, each of the methods **260**, **440**, and each of the systems **120**, **430** used to execute the respective methods **260**, **440**, may include or execute fewer than all of the shown blocks.

(56) For example, according to the first embodiment, as illustrated in FIG. **12**, a method **260** is provided for determining which engine of an aircraft **12** having a first engine **14** and a second engine **16** to start first for a taxiing operation **10** along a taxiway **104** at an airport **78**. The method **260** includes: (i) at block **270**, receiving or accessing historical fuel usage data **158** for each of the first and second engines **14**, **16**; (ii) at block **290**, receiving or accessing taxiway information **160** for the taxiing operation **10**; (iii) at block **300**, determining which of the first and second engines **14**, **16** to start before the other of the first and second engines **14**, **16**, thereby defining a first-to-start engine **17** and a second-to-start engine **19** respectively, based on optimizing one or more predetermined factors **212**; and (iv) at block **360**, producing a first-to-start alert **216** indicating which of the first and second engines **14**, **16** is the first-to-start engine **17**.

(57) According to the second embodiment, as illustrated in FIGS. **2** and **12**, a system **120** is provided for determining which engine of an aircraft **12** having a first engine **14** and a second engine **16** to start first for a taxiing operation **10** along a taxiway **104** at an airport **78**. The system **120** includes a determination module **122** and an indication module **124** operatively connected with the determination module **122**. The system **120** may be configured to execute or effectuate the method **260** of the first embodiment described above. The determination module **122** has a memory **126** configured to store an instruction set **128** and processing circuitry **130** configured to access the memory **126** and execute the instruction set **128** to: (i) receive or access historical fuel usage data **158** for each of the first and second engines **14**, **16** (see block **270**); (ii) receive or access taxiway information **160** for the taxiing operation **10** (see block **290**); (iii) determine which of the first and second engines **14**, **16** to start before the other of the first and second engines **14**, **16**, thereby

defining a first-to-start engine **17** and a second-to-start engine **19** respectively, based on optimizing one or more predetermined factors **212** (see block **300**); and (iv) produce a first-to-start alert signal **214** based on which of the first and second engines **14**, **16** is the first-to-start engine **17** (see block **290**). The indication module **124** is configured to receive the first-to-start alert signal **214** from the determination module **122** and produce a first-to-start alert **216** based on the first-to-start alert signal **214** (see block **360**).

(58) According to the third embodiment, as illustrated in FIGS. **5** and **12**, a method **440** is provided for estimating a total amount of fuel needed **254** by an aircraft **12** for conducting a taxiing operation **10** along a taxiway **104** at an airport **78**, with the aircraft **12** having a first engine **14** and a second engine **16**. The method **440** includes: (i) at block **270**, receiving or accessing historical fuel usage data **158** for each of the first and second engines **14**, **16**; (ii) at block **290**, receiving or accessing taxiway information **160** for the taxiing operation **10**; (iii) at block **300**, determining which of the first and second engines **14**, **16** to start before the other of the first and second engines **14**, **16**, thereby defining a first-to-start engine **17** and a second-to-start engine **19**, respectively, based on optimizing one or more predetermined factors **212**; (iv) at block **310**, determining an engine use plan **236** for executing the taxiing operation **10** based on the optimizing of the one or more predetermined factors **212** at block **300**, wherein the engine use plan **236** includes the steps or actions of starting the first-to-start engine **17** at a first timepoint T.sub.1, running the first-to-start engine **17** for a first time period **194** after the first timepoint T.sub.1, starting the second-to-start engine **19** at a second timepoint T.sub.2 at or after an end of the first time period T.sub.1, and running the first-to-start and second-to-start engines **17**, **19** for a second time period **196** after the second timepoint T.sub.2; (v) at block **320**, estimating the total amount of fuel needed **254** for executing the taxiing operation **10** based on the engine use plan **236**; and (vi) at block **340**, producing a fuel-estimate indication **258** indicating the estimated total amount of fuel needed **254**.

(59) According to the fourth embodiment, as illustrated in FIGS. **2**, **5** and **12**, a system **430** is provided for estimating a total amount of fuel needed **254** by an aircraft **12** for conducting a taxiing operation **10** along a taxiway **104** at an airport **78**, with the aircraft **12** having a first engine **14** and a second engine **16**. The system **430** includes a determination module **122** and an indication module **124** operatively connected with the determination module **122**. The system **430** may be configured to execute or effectuate the method **440** of the third embodiment described above. The determination module **122** has a memory **126** configured to store an instruction set **128** and processing circuitry **130** configured to access the memory **126** and execute the instruction set **128** to: (i) receive or access historical fuel usage data **158** for each of the first and second engines **14**, **16** (see block **270**); (ii) receive or access taxiway information **160** for the taxiing operation **10** (see block **290**); (iii) determine which of the first and second engines **14**, **16** to start before the other of the first and second engines **14**, **16**, thereby defining a first-to-start engine **17** and a second-to-start engine **19**, respectively, based on optimizing one or more predetermined factors **212** (see block **300**); (iv) determine an engine use plan **236** for executing the taxiing operation **10** based on the optimizing of the one or more predetermined factors **212**, wherein the engine use plan **236** includes starting the first-to-start engine **17** at a first timepoint T.sub.1, running the first-to-start engine **17** for a first time period **194** after the first timepoint T.sub.2, starting the second-to-start engine **19** at a second timepoint T.sub.2 at or after an end of the first time period T.sub.1, and running the first-to-start and second-to-start engines **17**, **19** for a second time period **196** after the second timepoint T.sub.2 (see block **310**); (v) estimate the total amount of fuel needed **254** for executing the taxiing operation **10** based on the engine use plan **236** (see block **320**); and (vi) produce a fuel-estimate indication signal **256** based on the estimated total amount of fuel needed **254** (see block **330**). The indication module **124** is configured to receive the fuel-estimate indication signal **256** from the determination module **122** and produce a fuel-estimate indication **258** based on the fuel-estimate indication signal **256** (see block **340**).

(60) In the above first embodiment, the method **260** may include, at block **310**, determining an

engine use plan **236** for executing the taxiing operation **10** based on the optimizing of the one or more predetermined factors **212**, wherein the engine use plan **236** includes starting the first-to-start engine **17** at a first timepoint T.sub.1, running the first-to-start engine **17** for a first time period **194** after the first timepoint T.sub.1, starting the second-to-start engine **19** at a second timepoint T.sub.2 at or after an end of the first time period, and running the first-to-start and second-to-start engines **17**, **19** for a second time period **196** after the second timepoint T.sub.2. Similarly, in the above second embodiment, the determination module **122** may be further configured to determine an engine use plan **236** for executing the taxiing operation **10** based on the optimizing of the one or more predetermined factors **212** (see block **310**), wherein the engine use plan **236** includes starting the first-to-start engine **17** at a first timepoint T.sub.1, running the first-to-start engine **17** for a first time period **194** after the first timepoint T.sub.1, starting the second-to-start engine **19** at a second timepoint T.sub.2 at or after an end of the first time period, and running the first-to-start and second-to-start engines **17**, **19** for a second time period **196** after the second timepoint T.sub.2.

(61) In the above first embodiment, the method **260** may include, at block **320**, estimating a total amount of fuel needed **254** for executing the taxiing operation **10** based on the engine use plan **236**, and optionally may additionally include one or both of producing a fuel-estimate indication signal **256** based on the estimated total amount of fuel needed **254** (at block **330**) and producing a fuel-estimate indication **258** indicating the estimated total amount of fuel needed **254** (at block **340**). Similarly, in the above second embodiment, the determination module **122** may be further configured to estimate a total amount of fuel needed **254** for executing the taxiing operation **10** based on the engine use plan **236** (see block **320**), and optionally may be further configured to produce a fuel-estimate indication signal **256** based on the estimated total amount of fuel needed **254** (see block **330**), and the indication module **124** may be configured to produce a fuel-estimate indication **258** based on the fuel-estimate indication signal **256** (see block **340**).

(62) In the above third embodiment, the method **440** may include, at block **330**, producing a fuel-estimate indication signal **256** based on the estimated total amount of fuel needed **254**.

(63) In one or both of the above first and third embodiments, the method **260**, **440** may include, at block **350**, producing a first-to-start alert signal **214** based on the determining of which of the first and second engines **14**, **16** is the first-to-start engine **17** at block **300**. Similarly, in one or both of the above second and fourth embodiments, the determination module **122** may be further configured to produce a first-to-start alert signal **214** based on which of the first and second engines **14**, **16** is the first-to-start engine **17** (see block **350**). Additionally, in the above third embodiment, the method **440** may include, at block **360**, producing a first-to-start alert **216** indicating which of the first and second engines **14**, **16** is the first-to-start engine **17**, and in the above fourth embodiment, the indication module **124** may be further configured to produce a first-to-start alert **216** based on the first-to-start alert signal **214** (see block **360**).

(64) In one or both of the above first and third embodiments, the method **260**, **440** may further include, at block **280**, receiving or accessing historical fuel use records **159** for one or more previous instances **202** of the taxiing operation **10**, wherein the historical fuel use records **159** are for the aircraft **12** and/or for other aircraft **15**. Similarly, in one or both of the above second and fourth embodiments, the determination module **122** may be further configured to receive or access historical fuel use records **159** for one or more previous instances **202** of the taxiing operation **10**, wherein the historical fuel use records **159** are for the aircraft **12** and/or for other aircraft **15** (see block **280**).

(65) In one or both of the above first and third embodiments, the method **260**, **440** may further include, at block **380**, producing a first-start-ready alert **248** indicating a first OK-to-proceed condition **195** for starting the first-to-start engine **17**, and optionally may further include, at block **410**, producing a second-start-ready alert **252** indicating a second OK-to-proceed condition **197** for starting the second-to-start engine **19**. Additionally, in one or both of the above first and third embodiments, the method **260**, **440** may further include, at block **370**, producing a first-start-ready

alert signal **246** based on the engine use plan **236**, and optionally may further include, at block **400**, producing a second-start-ready alert signal **250** based on the engine use plan **236**.

(66) In one or both of the above second and fourth embodiments, the indication module **124** may be further configured to produce a first-start-ready alert **248** indicating a first OK-to-proceed condition **195** for starting the first-to-start engine **17** (see block **380**), and optionally may be further configured to produce a second-start-ready alert **252** indicating a second OK-to-proceed condition **197** for starting the second-to-start engine **19** (see block **410**). Additionally, in one or both of the above second and fourth embodiments, the determination module **122** may be further configured to produce a first-start-ready alert signal **246** based on the engine use plan **236** (see block **370**), and optionally may be further configured to produce a second-start-ready alert signal **250** based on the engine use plan **236** (see block **400**).

(67) In one or both of the above first and third embodiments, the method **260**, **440** may further include, at block **390**, starting the first-to-start engine **17**, and optionally may further include, at block **420**, starting the second-to-start engine **19**. Similarly, in one or both of the above second and fourth embodiments, the determination module **122** may be further configured to start the first-to-start engine **17** (see block **390**), and optionally may be further configured to start the second-to-start engine **19** (see block **420**).

(68) In one or more of the above embodiments, and as illustrated in FIGS. **6**, **8** and **10**, the predetermined factors **212** may include one or more of minimizing a total amount of fuel consumed **224** for executing the taxiing operation **10** by the first and second engines **14**, **16** (block **222**), prioritizing whichever of the first and second engines **14**, **16** was started first in a most previous operating cycle **210** (block **226**), prioritizing whichever of the first and second engines **14**, **16** has a lower number of cumulative operating hours **230** (block **228**), and minimizing brake wear **234** for the aircraft **12** based on a number of turns **112** present in the taxiway **104** (block **232**). The predetermined factors **212** may be received by the aircraft **12** from one or more external databases, services or sources **84** (e.g., via the transceiver **70**), and/or the predetermined factors **212** may be recalled from an onboard storage medium (e.g., from memory **126** by processing circuitry **130**, and/or from storage medium **68** by accessing/processing circuit **64**).

(69) In one or more of the above embodiments, and as illustrated in FIGS. **3** and **7**, the taxiway **104** may include a plurality of taxiway features **105**, including one or more of a taxiway segment **106**, a runway (such as the arriving runway **100** and the departing runway **102**), an ascending ramp or segment **108**, a descending ramp or segment **110**, a divot **114** and a turn **112**. Others **116** of such taxiway features **105** are also possible. Each taxiway feature **105** may be associated with a respective subset **162** of the taxiway information **160**. Each subset **162** of the taxiway information **160** may include one or more of a respective set of latitude-longitude coordinates **164** representing a location **166** of the associated taxiway feature **105**, a respective set of one or more vectors **168** representing or characterizing a spatial orientation or directionality **170** of the associated taxiway feature **105**, a respective size **172** of the associated taxiway feature **105**, a respective shape **174** of the associated taxiway feature **105**, a respective slope **176** of the associated taxiway feature **105**, a respective elevation **178** of the associated taxiway feature **105**, a respective type **180** of the associated taxiway feature **105**, and a respective severity or impact rating **182** of how the associated taxiway feature **105** is likely to affect movement of the aircraft **12** across the taxiway feature **105**.

(70) In one or more of the above embodiments, and as illustrated in FIG. **7**, the taxiway information **160** may include data from one or more Notice to Air Mission (NOTAM) reports **184**, which are reports filed by flight personnel aboard aircrafts for use by other personnel aboard other aircrafts regarding information or issues that have not been previously known or announced. For example, a NOTAM **184** may report sudden severe weather that has been encountered, newly discovered debris on a taxiway **104**, etc. More specifically, the NOTAM data may include one or more both of historical data **186** from previous NOTAM reports **188** and real-time data **190** from current NOTAM reports **192**.

(71) In one or more of the above embodiments, and as illustrated in FIG. **2**, the alert **142**, the first-to-start alert **216**, the second-to-start alert **220**, the first-start-ready alert **248**, the second-start-ready alert **252** and the fuel estimate indication **258** may each comprise one or more of a visual indication **43** on a display device **30**, an auditory indication **51** through an auditory device **44**, and a vibratory indication **55** from a vibrational device **52**. These various alerts and indications may each be triggered or initiated by a respective alert signal **136** (for the alert **142**), a respective first-to-start alert signal **214** (for the first-to-start alert **216**), a respective second-to-start alert signal **218** (for the second-to-start alert **220**), a respective first-start-ready alert signal **246** (for the first-start-ready alert **248**), a respective second-start-ready alert signal **250** (for the second-start-ready alert **252**) and a respective fuel estimate indication signal **256** (for the fuel estimate indication **258**), as may be generated by the determination module **122** and received by the indication module **124**.
(72) In one or more of the above embodiments, the first-start-ready alert **248** (and optionally the first-start-ready alert signal **246**) may be based on completing the determination **123** of which engine **14**, **16** should be started first, and/or on determining some or all of the engine use plan **236**. For example, once a determination **123** has been made as to which engine **14**, **16** should be the first-to-start engine **17**, then a first-start-ready alert signal **246** may be sent by the determination module **122** to the indication module **124**, and the indication module **124** may then in turn send a command or power signal to one or more of the display, auditory and vibrational devices **30**, **44**, **52** so that a first-start-ready alert **248** is effected in order to inform the pilot **26**. Similarly, the second-start-ready alert **252** (and optionally the second-start-ready alert signal **250**) may also be based on completing the determination **123** and/or on determining some or all of the engine use plan **236**.
(73) While various steps of the methods **260**, **440** have been described as being separate blocks, and various functions of the system **120**, **430** have been described as being separate modules or elements, it may be noted that two or more steps may be combined into fewer blocks, and two or more functions may be combined into fewer modules or elements. Similarly, some steps described as a single block may be separated into two or more blocks, and some functions described as a single module or element may be separated into two or more modules or elements. Additionally, the order of the steps or blocks described herein may be rearranged in one or more different orders, and the arrangement of the functions, modules and elements may be rearranged into one or more different arrangements. Further, note that the controller **71** may optionally include some or all of the structure and/or function of the determination module **122** and/or of the indication module **124**.
(74) As used herein, a “module” may include hardware and/or software, including executable instructions, for receiving one or more inputs, processing the one or more inputs, and providing one or more corresponding outputs. Also note that at some points throughout the present disclosure, reference may be made to a singular input, output, element, etc., while at other points reference may be made to plural/multiple inputs, outputs, elements, etc. Thus, weight should not be given to whether the input(s), output(s), element(s), etc. are used in the singular or plural form at any particular point in the present disclosure, as the singular and plural uses of such words should be viewed as being interchangeable, unless the specific context dictates otherwise.
(75) The above description is intended to be illustrative, and not restrictive. While the dimensions and types of materials described herein are intended to be illustrative, they are by no means limiting and are exemplary embodiments. In the following claims, use of the terms “first”, “second”, “top”, “bottom”, etc. are used merely as labels, and are not intended to impose numerical or positional requirements on their objects. As used herein, an element or step recited in the singular and preceded by the word “a” or “an” should be understood as not excluding plural of such elements or steps, unless such exclusion is explicitly stated. Additionally, the phrase “at least one of A and B” and the phrase “A and/or B” should each be understood to mean “only A, only B, or both A and B”. Moreover, unless explicitly stated to the contrary, embodiments “comprising” or “having” an element or a plurality of elements having a particular property may include additional such elements not having that property. And when broadly descriptive adverbs such as

“substantially” and “generally” are used herein to modify an adjective, these adverbs mean “mostly”, “mainly”, “for the most part”, “to a significant extent”, “to a large degree” and/or “at least 51 to 99% out of a possible extent of 100%”, and do not necessarily mean “perfectly”, “completely”, “strictly”, “entirely” or “100%”. Additionally, the word “proximate” may be used herein to describe the location of an object or portion thereof with respect to another object or portion thereof, and/or to describe the positional relationship of two objects or their respective portions thereof with respect to each other, and may mean “near”, “adjacent”, “close to”, “close by”, “at” or the like.
(76) This written description uses examples, including the best mode, to enable those skilled in the art to make and use devices, systems and compositions of matter, and to perform methods, according to this disclosure. It is the following claims, including equivalents, which define the scope of the present disclosure.

Claims

1. A method for determining which engine of an aircraft having a first engine and a second engine to start first for a taxiing operation along a taxiway at an airport, comprising: receiving or accessing historical fuel usage data for each of the first and second engines; receiving or accessing taxiway information for the taxiing operation; optimizing one or more predetermined factors based at least on the historical fuel usage data or the taxiway information; selecting one of the first and second engines to start before the other of the first and second engines, thereby defining a first-to-start engine and a second-to-start engine, respectively, based on the optimizing the one or more predetermined factors; producing a first-to-start alert indicating which of the first and second engines is the first-to-start engine based on the selecting; and starting the first-to-start engine based on the selecting.
2. The method of claim 1, wherein the predetermined factors include one or more of: minimizing a total amount of fuel consumed for executing the taxiing operation by the first and second engines; prioritizing whichever of the first and second engines was started first in a most previous operating cycle; prioritizing whichever of the first and second engines has a lower number of cumulative operating hours; and minimizing brake wear for the aircraft based on a number of turns present in the taxiway.
3. The method of claim 1, further comprising: receiving or accessing historical fuel use records for one or more previous instances of the taxiing operation.
4. The method of claim 3, wherein the historical fuel use records are for the aircraft and/or for other aircraft.
5. The method of claim 1, wherein the taxiway includes a plurality of taxiway features, wherein each taxiway feature is associated with a respective subset of the taxiway information, and wherein each subset of the taxiway information includes one or more of: a respective set of latitude-longitude coordinates representing a location of the associated taxiway feature; a respective set of one or more vectors representing a spatial orientation of the associated taxiway feature; a respective size of the associated taxiway feature; a respective shape of the associated taxiway feature; a respective slope of the associated taxiway feature; a respective elevation of the associated taxiway feature; and a respective severity rating of how the associated taxiway feature affects movement of the aircraft thereacross.
6. The method of claim 5, wherein the taxiway features include one or more of a taxiway segment, a runway, an ascending ramp, a descending ramp, a divot and a turn.
7. The method of claim 1, wherein the taxiway information includes one or both of historical data from previous Notice to Air Mission (NOTAM) reports and real-time data from current NOTAM reports.
8. The method of claim 1, further comprising: determining an engine use plan for executing the

taxiing operation based on the optimizing of the one or more predetermined factors, wherein the engine use plan includes starting the first-to-start engine at a first timepoint, running the first-to-start engine for a first time period after the first timepoint, starting the second-to-start engine at a second timepoint at or after an end of the first time period, and running the first-to-start and second-to-start engines for a second time period after the second timepoint.

9. The method of claim 8, further comprising: producing a first-start-ready alert indicating a first OK-to-proceed condition for starting the first-to-start engine.

10. The method of claim 9, further comprising: producing a second-start-ready alert indicating a second OK-to-proceed condition for starting the second-to-start engine; and starting the second-to-start engine.

11. The method of claim 8, further comprising: estimating a total amount of fuel needed for executing the taxiing operation based on the engine use plan.

12. The method of claim 11, further comprising: producing a fuel-estimate indication indicating the estimated total amount of fuel needed.

13. A system for determining which engine of an aircraft having a first engine and a second engine to start first for a taxiing operation along a taxiway at an airport, comprising: a determination module having a memory configured to store an instruction set and processing circuitry configured to access the memory and execute the instruction set to: receive or access historical fuel usage data for each of the first and second engines; receive or access taxiway information for the taxiing operation; optimize one or more predetermined factors based on the historical fuel usage data or the taxiway information; select one of the first and second engines to start before the other of the first and second engines, thereby defining a first-to-start engine and a second-to-start engine, respectively, based on optimizing the one or more predetermined factors; and produce a first-to-start alert signal based on the select step; and the first-to-start engine configured to started based on the select step.

14. The system of claim 13, wherein the determination module is further configured to do one or more of the following: receive or access historical fuel use records for one or more previous instances of the taxiing operation; determine an engine use plan for executing the taxiing operation based on the optimizing of the one or more predetermined factors, wherein the engine use plan includes starting the first-to-start engine at a first timepoint, running the first-to-start engine for a first time period after the first timepoint, starting the second-to-start engine at a second timepoint at or after an end of the first time period, and running the first-to-start and second-to-start engines for a second time period after the second timepoint; produce a first-start-ready alert signal based on the engine use plan; produce a second-start-ready alert signal based on the engine use plan; estimate a total amount of fuel needed for executing the taxiing operation based on the engine use plan; and produce a fuel-estimate indication signal based on the estimated total amount of fuel needed.

15. The system of claim 13, wherein an indication module includes processing circuitry that is configured to receive the first-to-start alert signal and produce a first-to-start alert based on the first-to-start alert signal.

16. The system of claim 15, wherein the first-to-start alert comprises one or more of a visual indication on a display device, an auditory indication through an auditory device, and a vibratory indication from a vibrational device.

17. A method for estimating a total amount of fuel needed by an aircraft for conducting a taxiing operation along a taxiway at an airport, the aircraft having a first engine and a second engine, the method comprising: receiving or accessing historical fuel usage data for each of the first and second engines; receiving or accessing taxiway information for the taxiing operation; optimizing one or more predetermined factors based on the historical fuel usage data or the taxiway information; selecting one of the first and second engines to start before the other of the first and second engines, thereby defining a first-to-start engine and a second-to-start engine, respectively, based on the optimizing the one or more predetermined factors; determining an engine use plan for

executing the taxiing operation based on the optimizing of the one or more predetermined factors, wherein the engine use plan includes starting the first-to-start engine at a first timepoint, running the first-to-start engine for a first time period after the first timepoint, starting the second-to-start engine at a second timepoint at or after an end of the first time period, and running the first-to-start and second-to-start engines for a second time period after the second timepoint based on the selecting step; starting the first-to-start engine at the first timepoint based on the selecting step; estimating the total amount of fuel needed for executing the taxiing operation based on the engine use plan; producing a fuel-estimate indication indicating the estimated total amount of fuel needed.
18. The method of claim 17, wherein the predetermined factors include one or more of: minimizing a total amount of fuel consumed for executing the taxiing operation by the first and second engines; prioritizing whichever of the first and second engines was started first in a most previous operating cycle; prioritizing whichever of the first and second engines has a lower number of cumulative operating hours; and minimizing brake wear for the aircraft based on a number of turns present in the taxiway.
19. The method of claim 17, further comprising: receiving or accessing historical fuel use records for one or more previous instances of the taxiing operation, wherein the historical fuel use records are for the aircraft and/or for other aircraft.
20. The method of claim 17, wherein the taxiway includes a plurality of taxiway features including one or more of a taxiway segment, a runway, an ascending ramp, a descending ramp, a divot and a turn, wherein each taxiway feature is associated with a respective subset of the taxiway information, and wherein each subset of the taxiway information includes one or more of: a respective set of latitude-longitude coordinates representing a location of the associated taxiway feature; a respective set of one or more vectors representing a spatial orientation of the associated taxiway feature; a respective size of the associated taxiway feature; a respective shape of the associated taxiway feature; a respective slope of the associated taxiway feature; a respective directionality of the associated taxiway feature; and a respective severity rating of how the associated taxiway feature affects movement of the aircraft thereacross.