(54) Title: VEHICLE DIAGNOSTIC SYSTEM AND METHOD

(57) Abstract: Methods and apparatus for identifying faults in a vehicle (2) that includes a plurality of vehicle subsystems (4-12), the method comprising: for each vehicle subsystem (4-12), by a respective subsystem reasoner (30-38) corresponding to that vehicle subsystem (4-12), receiving and processing information from that vehicle subsystem (4-12); by a vehicle health reasoner (40), receiving and processing information from at least two different sources (selected from the group of sources consisting of each of the vehicle subsystems (4-12) and each of the subsystem reasoners (30-38)) to determine, for each of one or more further faults, a probability that that further fault has occurred, each further faults being a fault the symptoms of which manifest in more than one of the vehicle subsystems (4-12); and displaying an identity of the fault that corresponds to the highest probability.
FIELD OF THE INVENTION
The present invention relates to diagnosing faults in a vehicle.

BACKGROUND
Typically, the assessment of system health of aircraft, diagnosis of faults on those aircraft, and/or the maintenance of those aircraft involves the use of several information sources (e.g. technical manuals, etc.) and tools (e.g. fault diagnosis and test software that are bespoke to a particular aircraft system) that a person carrying out the maintenance needs to reference in order to effectively perform such a task.

Often these information sources and tools are provided on a plurality of different devices (e.g. specific laptops and test equipment) or in a plurality of different formats (e.g. in electronic form, as a paper manuals etc.).

Also, some processing of aircraft data that is performed during aircraft maintenance tends to be performed at a location that is remote from the aircraft. This tends to be inconvenient for the person carrying out the maintenance of the aircraft.

SUMMARY OF THE INVENTION
In a first aspect, the present invention provides a method of identifying faults in a vehicle. The vehicle comprises a plurality of vehicle subsystems. The method comprises: for each vehicle subsystem, receiving, by a respective subsystem reasoner corresponding to that vehicle subsystem, information from that vehicle subsystem, and, for each vehicle subsystem, using the information received from that vehicle subsystem, performing, by the respective subsystem reasoner corresponding to that vehicle subsystem, a fault diagnosis process to determine, for each of one or more subsystem faults, a probability that that
subsystem fault has occurred (each of the one or more subsystem faults is a fault the symptoms of which manifest in that vehicle subsystem). The method further comprises receiving, by a vehicle health reasoner, information from at least two different sources, the at least two different sources being selected from the group of sources consisting of: one or more of the vehicle subsystems and one or more of the subsystem reasoners, and, using the information received from the at least two different sources, performing, by the vehicle health reasoner, a further fault diagnosis process to determine, for each of one or more further faults, a probability that that further fault has occurred (each of the one or more further faults is a fault the symptoms of which manifest in more than one of the vehicle subsystems). The method further comprises displaying, on a display, at least an identity of the subsystem fault or further fault that corresponds to the highest probability.

The at least two different sources of information may include either: (i) two different vehicle subsystems; (ii) two different subsystem reasoners; or (iii) a subsystem reasoner and a vehicle subsystem that is different to the vehicle subsystem that corresponds to that subsystem reasoner.

The method may further comprise, for each vehicle subsystem, prior to the subsystem reasoner corresponding to that vehicle subsystem performing the fault diagnosis process, converting the information received from that vehicle subsystem into a common data format or standard.

The information received by the vehicle health reasoner may be in the common data format or standard.

The common data format or standard may be the MIMOSA(TM) Open Systems Architecture for Condition-Based Maintenance open data standard.

The subsystem reasoners and the vehicle health reasoner may be connected together by a data bus for passing information between the subsystem reasoners and the vehicle health reasoner.

Each subsystems reasoners may be located on the vehicle, or remote from vehicle. For example, one or more of the subsystem reasoners may be located in a Portable Maintenance Aid which may be located proximate to the
vehicle. The subsystem reasoners may be connected together by a network and data bus.

The vehicle may be an aircraft. The vehicle subsystems may be aircraft subsystems selected from the group of aircraft subsystems consisting of: a propulsion system, mechanical systems, a power system, a fuel system, a flight management system, an environmental control system, a hydraulics system, and a radar system.

The method may further comprise identifying at least one test to be performed in order to refine one or more of the probability values. The method may further comprise displaying, on the display, an indication of each identified test. The method may further comprise performing each identified test. The method may further comprise refining one or more of the probability values using the results of the performed test or tests. The method may further comprise updating one or more of the fault diagnosis processes using results of the performed test or tests.

The method may further comprise, for at least the displayed subsystem fault or further fault, identifying one or more remedial actions to be performed. The remedial actions may be such that, if the remedial actions were to be performed, that subsystem fault or further fault would be repaired. The method may further comprise displaying, on the display, an indication of each identified remedial action.

The method may further comprise, for each identified remedial action, identifying a set of instructions for performing that remedial action. The method may further comprise displaying, on the display, each identified set of instructions. Displaying a set of instructions may comprise displaying some or all of an integrated electronic technical manuals relating to one or more of the vehicle systems.

The subsystem reasoners and the vehicle health reasoner may be located within a Portable Maintenance Aid.

The steps of receiving data from the vehicle subsystems may comprise, for each vehicle subsystem, connecting the Portable Maintenance Aid to that
vehicle subsystem and downloading information from that vehicle subsystem on
to the Portable Maintenance Aid.

Each fault diagnosis processes may comprise providing a fault-symptom
model comprising a probabilistic Bayesian network and, using the Bayesian
network, performing Bayesian inference so as to determine a probability for one
or more faults. Each health assessment process may comprise other
probabilistic methods instead of or in addition the Bayesian process. Example
processes include, but are not limited to, Support Vector Machine based
processes, Regression based processes, Decision Tree based processes, etc.

In a further aspect, the present invention provides apparatus for
identifying faults in a vehicle. The vehicle comprises a plurality of vehicle
subsystems. The apparatus comprises a plurality of subsystem reasoners, a
vehicle health reasoner, and a display. Each subsystem reasoner is configured
to receive information from a respective vehicle subsystem, and, using the
information received by that subsystem reasoner, perform a fault diagnosis
process to determine, for each of one or more subsystem faults, a probability
that that subsystem fault has occurred (each of the one or more subsystem
faults is a fault the symptoms of which manifest in the vehicle subsystem from
which that subsystem reasoner received information). The vehicle health
reasoner is configured to receive information from at least two different sources
selected from the group of sources consisting of one or more of the vehicle
subsystems and one or more of the subsystem reasoners. The vehicle health
reasoner is further configured to, using information received from the at least
two different sources, perform a further fault diagnosis process to determine, for
each of one or more further faults, a probability that that further fault has
occurred (each of the one or more further faults is a fault the symptoms of which
manifest in more than one of the vehicle subsystems). The display is configured
to display at least an identity of the subsystem fault or further fault that
corresponds to the highest probability.

In a further aspect, the present invention provides a method of assisting
in an assessment of a vehicle, the vehicle comprising a plurality of vehicle
systems, the method comprising receiving, by a portable maintenance aid,
data from one or more of the vehicle systems, using the received data, performing, by the portable maintenance aid, a fault diagnosis process to determine an output, and displaying, on a display of the portable maintenance aid, the output, wherein the output comprises either an indication of a state or condition of one or more of the vehicle systems, an indication that one or more faults has occurred, each fault being a fault in one or more of the vehicle systems, or a proposal or a recommendation that an action be performed, the action is such that, if the action is performed, further data would be provided for use by the portable maintenance aid, and the further data is such that, if the further data were used by the portable maintenance aid in the performance of the fault diagnosis process, the accuracy of the fault diagnosis process would be increased compared to if the further data were not used by the portable maintenance aid in the performance of the fault diagnosis process.

If the output comprises an indication that one or more faults has occurred, the output may further comprise, for each fault that it is indicated has occurred, a probability or likelihood that that fault has occurred.

If the output comprises an indication that one or more faults has occurred, the output may further comprise: a proposal or a recommendation that a further action be performed, the further action is such that, if the further action is performed, the fault would be repaired, and a set of instructions for performing the further action.

If the output comprises a proposal or a recommendation that an action be performed, the output may further comprise a set of instructions for performing the action.

Displaying the set of instructions may comprise displaying some or all of an integrated electronic technical manuals relating to one or more of the vehicle systems.

If the output comprises a proposal or a recommendation that an action be performed, the method may comprise, in response to the action being performed, using the further data, performing, by the portable maintenance aid,
the fault diagnosis process to determine a further output, and displaying, on the display, the further output.

The step of receiving data from one or more of the vehicle systems may comprise, for each of the one or more of the vehicle systems from which data is to be received, in turn, connecting the portable maintenance aid to that vehicle system, and downloading, from that vehicle system on to the portable maintenance aid, data.

The method may further comprise, after receiving data from one or more of the vehicle systems and prior to, using that received data, performing the fault diagnosis process, converting that received data into a common data format or standard.

The common data format or standard may be the MIMOSA(TM) Open Systems Architecture for Condition-Based Maintenance open data standard.

The fault diagnosis process may comprise providing a fault/symptom model, the fault/symptom model comprising a probabilistic Bayesian network, and, using the Bayesian network, performing Bayesian inference so as to diagnose a fault in a vehicle system.

The vehicle may be an aircraft. Also, the vehicle systems may be aircraft systems selected from the group of aircraft systems consisting of: a propulsion system, mechanical systems, a power system, a fuel system, a flight management system, an environmental control system, a hydraulics system, and a radar system.

In a further aspect, the present invention provides a portable maintenance aid for assisting in the health assessment and maintenance of a vehicle, the vehicle comprising a plurality of vehicle systems, the portable maintenance aid comprising receiving means configured to receive data from one or more of the vehicle systems, one or more processors operatively coupled to the receiving means and configured to, using received data, perform a fault diagnosis process to determine an output, and a display operatively coupled to the one or more processors and configured to display the output, wherein the output comprises either an indication that one or more faults has
occurred, each fault being a fault in one or more of the vehicle systems, or a proposal or a recommendation that an action be performed, the action is such that, if the action is performed, further data would be provided for use by the portable maintenance aid, and the further data is such that, if the further data were used by the portable maintenance aid in the performance of the fault diagnosis process, the accuracy of the fault diagnosis process would be increased compared to if the further data were not used by the portable maintenance aid in the performance of the fault diagnosis process.

The portable maintenance aid may further comprise a memory that may be operatively coupled to the processor. The memory may be configured to store a fault/symptom model, the fault/symptom model comprising a probabilistic Bayesian network for use in the fault diagnosis process. The memory may be further configured to store one or more sets of instructions for performing the action. The one or more processors may be further configured to perform the fault diagnosis process by, using the Bayesian network, performing Bayesian inference so as to diagnose a fault in a vehicle system. The receiving means may be further configured to be connected to one or more of the vehicle systems such that data from those vehicle systems may be downloaded on to the portable maintenance aid.

In a further aspect, the present invention provides a computer program or plurality of computer programs arranged such that when executed by a computer system it/they cause the computer system to operate in accordance with the method of any of the above aspects.

In a further aspect, the present invention provides a machine readable storage medium storing a computer program or at least one of the plurality of computer programs according to the previous aspect.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic illustration (not to scale) of an example of an aircraft;
Figure 2 is a schematic illustration (not to scale) of a portable maintenance aid;

Figure 3 is a schematic illustration (not to scale) of a reasoning module; and

Figure 4 is a process flow-chart showing certain steps of an embodiment of a method of performing aircraft maintenance.

DETAILED DESCRIPTION

Figure 1 is a schematic illustration (not to scale) of an example of an aircraft 2 using which an embodiment of a method of performing aircraft maintenance is to be implemented. The method of performing aircraft maintenance is described in more detail later below with reference to Figure 4.

The aircraft 2 is a conventional aircraft. The aircraft 2 may be a manned or an unmanned aircraft. The aircraft 2 is a system that comprises a plurality of different subsystems including, but not limited to, a propulsion system 4, mechanical systems 6, a power system 8, a fuel system 10, and a flight management system 12. An embodiment of the method of performing aircraft maintenance (described below with reference to Figure 4) will be described with reference to the example aircraft subsystems 4-12 shown in Figure 1. However, in other embodiments, the method of performing aircraft maintenance may be implemented using one or more different subsystems instead of or in addition to those subsystems 4-12 shown in Figure 1 and described herein. In some embodiments, the aircraft 2 further comprises additional subsystems, for example, an environmental control system, a hydraulics system, a radar system, which may be used during an aircraft maintenance process.

The propulsion system 4 may, for example, include primary and auxiliary propulsion units for generating thrust and/or lift. The propulsion system 4 may, for example, include gas turbines, propellers, ducted fans etc. The propulsion system 4 may, for example, include one or more computers or other processing
apparatus or processors from which data relating to a state or operations of the propulsion system 4 may be downloaded.

The mechanical systems 6 may include, for example, gearboxes, driveshafts, or other mechanical systems e.g. that may be driven a different system or unit. The mechanical systems 6 may, for example, include one or more computers or other processing apparatus or processors from which data relating to a state or operations of the mechanical systems 6 may be downloaded.

The power systems 8 may comprise electrical power and power distribution systems for providing electrical power to other aircraft systems. The power system 8 may, for example, include one or more computers or other processing apparatus or processors from which data relating to a state or operations of the power system 8 may be downloaded.

The fuel system 10 may comprise fuel storage, monitoring, and distribution systems. The fuel system 10 may, for example, comprise fuel tanks, supply lines, fuel level, temperature and/or pressure sensors, etc. The fuel system 10 may, for example, include one or more computers or other processing apparatus or processors from which data relating to a state or operations of the fuel system 10 may be downloaded.

The flight management system 12 may comprise one or more computers or other processing apparatus or processors for automating certain in-flight processes. The flight management system 12 may, for example, include one or more computers or other processing apparatus or processors from which flight data and/or data relating to a state or operations of the flight management system 12 may be downloaded.

Figure 2 is a schematic illustration (not to scale) showing an embodiment of a portable maintenance aid 14 used in the performance of the method of performing aircraft maintenance.

The portable maintenance aid 14 comprises one or more input ports 16, a user input device 18, a reasoning module 20, a memory 22, and a display 24.
The portable maintenance aid 14 is a mobile computing device that may be used during aircraft maintenance processes. The hardware components of the portable maintenance aid 14 (i.e. the input ports 16, the user input device 18, the reasoning module 20, the memory 22, and the display 24) may be conventional components. Further information on portable maintenance aids and the components thereof may be found, for example, in "Portable Maintenance Aids", LG005T2, July 2001, Gerald W. Bapst, Steven W. Butcher, Regina S. Clifford, Robert L. Jordan, which is incorporated herein by reference.

The input ports 16 provide means for connecting the portable maintenance aid 14 to each of the above mentioned aircraft subsystems 4-12. The connection of the portable maintenance aid 14 to each of the above mentioned aircraft subsystems 4-12 may, for example, be performed by connecting the input port 16 directly to an aircraft subsystem 4-12 or by using an adaptor or connection cable to connect the input port 16 to an aircraft subsystem 4-12. This connection of the portable maintenance aid 14 to an aircraft subsystem 4-12 via the input port 16 is such that data from that aircraft subsystem 4-12 may be downloaded onto the portable maintenance aid, as described in more detail later below with reference to Figure 4.

The user input device 18 may for example comprise a keyboard, a mouse, a touch screen display, or voice recognition capability. The user input device 18 enables a user of the portable maintenance aid 14 to input information into the portable maintenance aid 14.

The reasoning module 20 is connected to the input ports 16 and the user input device 18 such that information/data received at the input ports 16 and/or the user input device 18 may be sent to the reasoning module 20. The reasoning module 20 is described in more detail later below with reference to Figure 3. The reasoning module 20 is configured to process received information, as described in more detail later below with reference to Figure 4.

The reasoning module 20 is further connected to the memory 22 such that information stored on the memory 22 may be acquired by the reasoning module 20 from the memory 22 and processed by the reasoning module 20.
The memory 22 is configured to store aircraft data including, but not limited to, aircraft configuration data, parts reference information, test data, and aircraft calculations. In this embodiment, the memory 22 stores fault/symptom models 26 (e.g. Bayesian networks) relating to the aircraft 2 and its subsystems 4-12. The memory may also store diagnostic, prognostic, health assessment and test applications 28. The applications 28, when run by the reasoning module 20, may use data received from an aircraft subsystem 4-12 and the models 26 to diagnose faults within that aircraft subsystem 4-12.

The terminology "fault" is used herein to refer to a physical cause of anomalous behaviour within a system (i.e. a symptom), and/or a condition of a machine/system that occurs when one or more of its components or assemblies degrades or exhibits abnormal behaviour, which may lead to the failure of that machine/system. The terminology "failure" is used herein to refer to a loss of an ability of a system to perform some intended function. The terminology "diagnosis" is used herein to refer to conclusion(s) inferred from tests, observations, or other information and drawn about a system or unit under test. Further information about faults and fault diagnosis may be found in "Integrated Vehicle Health Management - Perspectives on an Emerging Field" Ian K Jennions, SAE International standards body, which is incorporated herein by reference.

In this embodiment, the models 26 and the applications 28 are those described in more detail in WO2009/1 361 83 "Assisting Failure Diagnosis in a System", which is incorporated herein by reference. In particular, the models 26 may include one or more probabilistic Bayesian Networks, and the applications 28 may perform operations based on Bayesian inference in order to diagnose faults in an aircraft subsystem 4-12. In other embodiments, a different type of reasoner may be used to diagnose faults in an aircraft subsystem 4-12 etc. For example, a different type of Diagnostic Reasoner (i.e. a system that uses a knowledge base to infer conclusions) may be used. A reasoner may use techniques other than probabilistic Bayesian Networks such as a Neural Network or Support Vector Machine.
The memory 22 also stores technical data 30 relating to one or more of the aircraft subsystems 4-12. For example, the memory 22 may store one or more integrated electronic technical manuals (IETMs) relating to an aircraft subsystem 4-12. Further information on IETMs may be found, for example, in "Portable Maintenance Aids", LG005T2, July 2001, Gerald W. Bapst, Steven W. Butcher, Regina S. Clifford, Robert L. Jordan, which is incorporated herein by reference.

The reasoning module 20 is further connected to the display 24 such that an output of the reasoning module 20 may be displayed on the display 24, e.g. to a user of the portable maintenance aid 14. The display 24 may be a touch screen display.

In this embodiment, hardware of the portable maintenance aid 14 tends to be advantageously rugged and user-friendly. For example, the operation of the portable maintenance aid 14 tends to be resistant to the effects of moisture, corrosion, vibration, electromagnetic interference, and extreme heat and coldness. The portable maintenance aid 14 may also comprise photo sensor technology to enhance sunlight readability. The portable maintenance aid 14 may be advantageously lightweight and easy for a user to carry. For example, the portable maintenance aid 14 may be a handheld device.

Figure 3 is a schematic illustration (not to scale) showing the reasoning module 20.

In this embodiment the reasoning module 20 comprises a plurality of subsystem reasoners 30-38, and an aircraft health reasoner 40.

In this embodiment, a first subsystem reasoner 30 is a diagnostic reasoner configured to process data output by the propulsion system 4. The first sub-system reasoner 30 is configured to perform a fault diagnosis operation so as to determine, based on data from the propulsion system 4, likely faults with the propulsion system 4. In this embodiment, the fault diagnosis operation performed by the first subsystem reasoner 30 may include performing a Bayesian inference process to determine probabilities (in view of the data) for a number of different possible propulsion system faults. A propulsion system fault
may be a fault the symptoms of which manifest (e.g. only) in the propulsion system 4. In other embodiments, different type of diagnostic processes may be performed instead of or in addition the Bayesian inference process. The first subsystem reasoner 30 may also compute "information-for-cost values" for symptoms that have not yet been observed so far.

In this embodiment, a second subsystem reasoner 32 is a diagnostic reasoner configured to process data output by the mechanical system 6. The first sub-system reasoner 30 is configured to perform a fault diagnosis operation so as to determine, based on data from the mechanical system 6, likely faults with the mechanical system 6. In this embodiment, the fault diagnosis operation performed by the second subsystem reasoner 32 may include performing a Bayesian inference process to determine probabilities (in view of the data) for a number of different possible mechanical system faults. A mechanical system fault may be a fault the symptoms of which manifest (e.g. only) in the mechanical system 6. In other embodiments, different type of diagnostic processes may be performed instead of or in addition the Bayesian inference process. The second subsystem reasoner 32 may also compute "information-for-cost values" for symptoms that have not yet been observed so far.

In this embodiment, a third subsystem reasoner 34 is a diagnostic reasoner configured to process data output by the power system 8. The first sub-system reasoner 30 is configured to perform a fault diagnosis operation so as to determine, based on data from the power system 8, likely faults with the power system 8. In this embodiment, the fault diagnosis operation performed by the third subsystem reasoner 34 may include performing a Bayesian inference process to determine probabilities (in view of the data) for a number of different possible power system faults. A power system fault may be a fault the symptoms of which manifest (e.g. only) in the power system 8. In other embodiments, different type of diagnostic processes may be performed instead of or in addition the Bayesian inference process. The third subsystem reasoner 34 may also compute "information-for-cost values" for symptoms that have not yet been observed so far.
In this embodiment, a fourth subsystem reasoner 36 is a diagnostic reasoner configured to process data output by the fuel system 10. The first subsystem reasoner 30 is configured to perform a fault diagnosis operation so as to determine, based on data from the fuel system 10, likely faults with the fuel system 10. In this embodiment, the fault diagnosis operation performed by the fourth subsystem reasoner 36 may include performing a Bayesian inference process to determine probabilities (in view of the data) for a number of different possible fuel system faults. A fuel system fault may be a fault the symptoms of which manifest (e.g. only) in the fuel system 10. In other embodiments, different type of diagnostic processes may be performed instead of or in addition the Bayesian inference process. The fourth subsystem reasoner 36 may also compute "information-for-cost values" for symptoms that have not yet been observed so far.

In this embodiment, a fifth subsystem reasoner 38 is a diagnostic reasoner configured to process data output by the flight management system 12. The first sub-system reasoner 30 is configured to perform a fault diagnosis operation so as to determine, based on data from the flight management system 12, likely faults with the flight management system 12. In this embodiment, the fault diagnosis operation performed by the fifth subsystem reasoner 38 may include performing a Bayesian inference process to determine probabilities (in view of the data) for a number of different possible flight management system faults. A flight management system fault may be a fault the symptoms of which manifest (e.g. only) in the flight management system 12. In other embodiments, different type of diagnostic processes may be performed instead of or in addition the Bayesian inference process. The fifth subsystem reasoner 38 may also compute "information-for-cost values" for symptoms that have not yet been observed so far.

In this embodiment, the aircraft health reasoner 40 is a diagnostic reasoner configured to process outputs from multiple subsystem reasoners 30-38. Also, the aircraft health reasoner 40 is further configured to process data from multiple aircraft subsystems 4-12. The aircraft health reasoner 40 is configured to perform a fault diagnosis operation so as to determine likely faults
with the aircraft 2 that may, for example, manifest as symptoms in multiple
aircraft subsystems 4 - 12. Such faults are hereinafter referred to as "aircraft
faults". The aircraft health reasoner 40 is configured to perform a fault diagnosis
operation so as to provide an assessment of the overall health of the aircraft 2.

In this embodiment, the fault diagnosis operation performed by the aircraft
health reasoner 40 may include performing a Bayesian inference process to
determine probabilities (in view of the data) for a number of different possible
aircraft faults. In other embodiments, different type of diagnostic processes may
be performed instead of or in addition the Bayesian inference process. The
aircraft health reasoner 38 may also compute "information-for-cost values" for
symptoms that have not yet been observed so far.

In this embodiment, the subsystem reasoners 30-38 and the aircraft
health reasoner 40 are connected together via a data bus 42. The data bus 42
connects the reasoners 30 - 40 such that information may be sent between the
reasoners 30 - 40. For example, the data bus 42 connects the subsystem
reasoners 30 - 38 to the aircraft health reasoner 40 such that outputs of
multiple subsystem reasoners 30 - 38 may be acquired, for processing, by the
aircraft health reasoner 40. Furthermore, the data bus 42 connects the
reasoners 30 - 40 to the input ports 16 such that data from the aircraft
subsystems 4 - 12 may be acquired, via the data bus 42, by the reasoners 30 -
40.

In this embodiment, data that is transferred over the data bus 42 is in a
data format or standard that is useable by each of the reasoners 30 - 40. The
data format that is useable by all of the subsystem reasoners 30 - 38 and the
aircraft health reasoner 40 is hereinafter referred to as the "common data
format". In this embodiment, the subsystem reasoners 30-38 and the aircraft
health reasoner 40 are configured to process information in that is in the
common data format. The common data format may be an open data standard
such as a data standard developed by MIMOSA(TM), e.g. MIMOSA(TM) Open
Systems Architecture for Condition-Based Maintenance (OSA-CBM).

Apparatus, including the reasoners 30-40, for implementing the above
arrangement, and performing the method steps to be described later below,
may be provided by configuring or adapting any suitable apparatus, for example one or more computers or other processing apparatus or processors, and/or providing additional modules. The apparatus may comprise a computer, a network of computers, or one or more processors, for implementing instructions and using data, including instructions and data in the form of a computer program or plurality of computer programs stored in or on a machine readable storage medium such as computer memory, a computer disk, ROM, PROM etc., or any combination of these or other storage media.

Figure 4 is a process flow-chart showing certain steps of an embodiment of a method of performing aircraft maintenance. In this embodiment, the aircraft maintenance is performed on the aircraft 2.

At step s2, the user of the portable maintenance aid 14 (i.e. the person performing aircraft maintenance on the aircraft 2) connects the portable maintenance aid 14 (via the input port 16) to a subsystem 4-12 of the aircraft 2. For example, the portable maintenance aid 14 may be connected via the input port 16 to the flight management subsystem 12.

At step s4, data relating to a state or operation of the aircraft subsystem 4-12 to which the portable maintenance aid 14 is connected are downloaded onto the portable maintenance aid 14.

At step s6, the downloaded data is converted (e.g. by conversion module included in the input port module 16) into the common data format that is useable by the reasoners 30 - 40.

At step s7, the converted data is stored by the memory 22 of the portable maintenance aid 14, for example, such that each of the reasoners 30 - 40 may acquire the converted data from the memory 22. For example, flight data and/or data relating to operation of the flight management subsystem 12 is downloaded, converted, and stored onto the portable maintenance aid 14 such that that data is accessible by at least the fifth subsystem reasoner 38 (which is configured to process data from the flight management subsystem 12).

In this embodiment, steps s2 to s7 are repeated for each aircraft subsystems 4-12 such that data relating to a state or operation of each of the
aircraft subsystems 4-12 is downloaded, converted, and stored on the portable maintenance aid 14.

If a fault exists within an aircraft subsystem 4 -12, the converted data acquired from that aircraft subsystem 4 - 12 tends to be indicative of one or more symptom(s) of that fault. Similarly, if an aircraft fault that affects multiple aircraft sub-systems exists, the converted data acquired from those aircraft subsystems 4 - 12 tends to be indicative of one or more symptom(s) of that aircraft fault.

At step s8, for each aircraft subsystem 4 -12, the data acquired from an aircraft subsystem 4 - 12 (that has been converted into a common format and stored in the memory 22) is processed by the relevant subsystem reasoner 30 - 38. In this embodiment, each of the subsystem reasoners 30 - 34 performs a fault diagnosis process using data received from the relevant aircraft subsystem 4 - 12. For example, using the data acquired from the propulsion system 4, and the models 26 and applications 28 stored in the memory 22, the first subsystem reasoner 30 performs a fault diagnosis operation to determine probabilities for a number of different propulsion system faults. An appropriate fault diagnosis operation is as described in more detail in WO2009/1 361 83 "Assisting Failure Diagnosis in a System", which is incorporated herein by reference. The first subsystem reasoner 30 may also compute "information-for-cost values" for symptoms that have not yet been observed so far.

Similarly, using the data acquired from the mechanical system 6, and the models 26 and applications 28, the second subsystem reasoner 32 performs a fault diagnosis operation so as to determine probabilities for a number of different mechanical system faults, and so on.

At steps s9, using the models 26 and applications 28 stored in the memory 22, the aircraft health reasoner 40 performs a fault diagnosis operation so as to determine probabilities for a number of different aircraft faults, each of which may manifest as symptoms in multiple different aircraft subsystems 4 - 12. The aircraft health reasoner 40 uses the models 26 and applications 28 to
determine an assessment of the overall health of the aircraft 2. In some
embodiments, the fault diagnosis operation includes the aircraft health reasoner
40 processing outputs of multiple different subsystem reasoners 30-38
(determined at step s8). In some embodiments, the fault diagnosis operation
includes the aircraft health reasoner 40 processing data from multiple different
aircraft subsystems 4 - 12. In some embodiments, the fault diagnosis operation
includes the aircraft health reasoner 40 processing outputs of one or more
subsystem reasoners 30-38 together with data from one or more aircraft
subsystem 4 - 12. In this embodiment, the information processed by the aircraft
health reasoner 40 is in the common data format and is acquired by the aircraft
health reasoner 40 via the bus 42.

At step s10, it is determined whether or not the process of Figure 3
should end, i.e. be stopped.

For example, each of the reasoners 30 - 40 may determine that the
method of performing aircraft maintenance should end because they have each
received and processed all relevant data from the aircraft 2. Also, it may be
determined that the method of performing aircraft maintenance should end
because the data downloaded from the aircraft indicates there are no faults to
be detected.

However, it may determined, by one or more of the subsystem reasoners
30 - 38 and/or the aircraft health reasoner 40, that the processing of further
information (e.g. further information that may be downloaded from an aircraft
subsystem 4-12, or supplied by the user of the portable maintenance aid 14)
may lead to a refinement of a fault diagnosis, and that the method of performing
aircraft maintenance should continue.

If, at step s10, it is determined that the method of performing aircraft
maintenance (i.e. the method of Figure 3) should be stopped, the method
proceeds to step s12.

However, if, at step s10, it is determined that the method of performing
aircraft maintenance (i.e. the method of Figure 3) should continue, i.e. should
not be stopped, the method proceeds to step s16, which will be described in more detail later below after the description of steps s12 to s15.

At step s12, outputs of the fault diagnosis operations performed by the reasoners 30 - 40 are displayed, on the display 24, to the user of the portable maintenance aid 14. In this embodiment, at step s12, it may be displayed to the user that no aircraft system faults have occurred. Alternatively, it may also be displayed to the user that one or more subsystem faults and/or aircraft faults may have occurred. These possible faults may be displayed to the user with corresponding probabilities of occurrence. Preferably, at least the fault that is most likely to have occurred is displayed to the user.

Further information may also be displayed to the user. For example, suggestions or recommendations to the user for one or more actions (e.g. investigating a particular part of the aircraft 2 or repairing or replacing a part of the aircraft 2) to be performed may be displayed to the user. Also, information (in the form of text, audio, video, images, etc.) may be presented to the user to aid the user in the investigation and/or repair of the one or more diagnosed faults. For example, one or more pages of a relevant IETM may be displayed to the user. Also, for example, instructions on how to investigate and/or repair the one or more diagnosed faults may be displayed to the user on the display 24.

At step s14, the user performs an action depending on the information displayed to him at step s12. For example, if no fault has been detected/diagnosed, the user may clear the aircraft 2 for flight. Also for example, if faults have been detected, the user may investigate and/or fix the one or more diagnosed faults. This may be done in accordance with any instructions provided to the user at step s12.

At step s15, data relating to the performance of the action by the user may be input into the portable maintenance aid 14. For example, if at step s12 it is displayed to the user that one or more aircraft system faults may have occurred, and the user, upon inspection of the aircraft 2, finds that those faults have indeed occurred, the user may indicate to the portable maintenance aid 14 that those faults have occurred. Likewise, if at step s12 it is displayed to the
user that one or more aircraft system faults may have occurred, and the user finds that those faults have not occurred, the user may indicate to the portable maintenance aid 14 that those faults have not occurred. This data may be stored in the memory 22. This data may be used to update the fault diagnosis operation to increase the accuracy of future diagnoses.

After step s15, the process of Figure 3 may end.

Returning now to the case where, at step s10, it is determined that the method of performing aircraft maintenance should continue, at step s16, outputs of the fault diagnosis operations performed by the reasoners 30 - 40 are displayed, on the display 24, to the user of the portable maintenance aid 14. It may also be displayed to the user that one or more subsystem faults or aircraft faults may have occurred. These possible faults may be displayed to the user with corresponding probabilities of occurrence. For example, a list of possible subsystem faults or aircraft faults may be displayed to the user. Also, the probabilities or likelihoods of those faults having occurred may also be displayed. Also, an indication of further data that may increase the accuracy of a fault diagnosis process may be displayed to the user.

In this embodiment, one or more recommended actions are displayed to the user. In other words, the portable maintenance aid 14 suggests or recommends to the user that one or more actions be performed in order to increase the accuracy of a fault diagnosis process. These actions and an estimate benefit of each action may be displayed to the user. This would advantageously indicate to the user which symptom's absence/presence should be inspected next.

Further information may also be displayed to the user. For example, information (in the form of text, audio, video, images, etc.) may be presented to the user to aid the user in the performance of one or more of the recommended actions. For example, one or more pages of a relevant IETM may be displayed to the user. Also, for example, instructions on how to carry out one or more of the recommended actions may be displayed to the user.
At step s18, the user performs the one or more recommended actions displayed to him at step s16. For example, the user may perform each recommend action that the reasoners 30 - 40 have determined would tend to increase the accuracy of a fault diagnosis process. Also, the user may perform the recommend action that corresponds to the best "information-for-cost value".

An action performed at step s18 may, for example, comprise the user connecting the portable maintenance aid 14 (via the input port 16) to a subsystem 4-12 of the aircraft 2 such that data that had not previously been downloaded onto the portable maintenance aid 14 may be downloaded onto the portable maintenance aid 14. Also for example, an action performed at step s18 may, for example, comprise the user inspecting part of the aircraft 2 or an aircraft subsystem 4-12.

At step s20, data relating to the one or more actions performed by the user at step s18 is input into, or downloaded onto, the portable maintenance aid 14. For example, if the action performed at step s18 comprised the user inspecting part of the aircraft 2 or an aircraft subsystem 4-12, the user may input (e.g. using the user input device 18) their observations or the results of the inspection. Also, if the action performed at step s18 comprised the user connecting the portable maintenance aid 14 (via the input port 16) to a subsystem 4-12 of the aircraft 2 in order to retrieve further data from that subsystem 4-12, that further data may be downloaded from that subsystem 4-12 onto the portable maintenance aid 14.

After step s20, the process of Figure 3 reverts back to step s6 where the data that was input or downloaded at step s20 is converted into a common format. The fault diagnosis operation may then be updated, or re-performed, using the further data, for example, instead of or in addition to some or all of the data previously used. The results of the fault diagnosis operation may then be displayed and the process may end or further actions may be performed by the user.

Thus, a method of performing aircraft maintenance is provided.
The above described system and method advantageously tends to reduce the maintenance burden of aircraft maintenance crew, for example, by providing the person performing the maintenance with recommended actions to perform. The recommended actions tend to be presented to the person performing the maintenance in a clear and easy to understand way. Also, the portable maintenance aid tends to be convenient to use. Thus, recommended actions can be presented to the use whilst maintenance is being performed, i.e. at the site of the maintenance.

A further advantage provided by the above described system and method is that the filtering of data tends to be robust and effective. Also, the above described system and method may detect shortfalls in data and notify maintenance crews that more data is required.

The above described system and method tend to improve aircraft safety and availability.

The above described system and method advantageously tend to mean that fewer pieces of equipment may be required to perform aircraft maintenance. This tends to reduce costs associated with certifying equipment for use with aircraft. Furthermore, storage and transport costs etc. associated with such equipment tend to be reduced.

The above described system and method advantageously tend to alleviate the problem of unnecessary maintenance, repairs, or equipment removals being performed.

The above described system and method advantageously tend to reduced the level of skill that required by a person to perform maintenance. This advantageously tends to reduce personnel training costs

The above described system and method advantageously tend to improve diagnostic accuracy.

The above described system and method advantageously tend to provide a learning diagnostics capability.
The above described system and method advantageously tend to reduce maintenance time and cost.

The above described system and method advantageously uses an open data standard (e.g. MIMOSA(TM) OSA-CBM. This tends to provide that a single device (e.g. a single portable maintenance aid) can be used to perform maintenance on a number of different types of vehicle e.g. a single portable maintenance aid may connect to a number of different aircraft platforms, systems and information sources, and process data downloaded therefrom.

The above described system and method advantageously tend to be able to combine modular processing (e.g. testing, diagnostics and prognostics) with data acquisition to guide a person performing maintenance through the steps of finding and/or repairing a fault. Furthermore, the person may be provided with the relevant information and advice at the right time.

Advantageously, the above described system and method may be used to diagnose (or predict) faults whose symptoms are present only in single aircraft subsystems, and also faults whose symptoms manifest in multiple aircraft subsystems. This tends to be facilitated by providing a plurality of separate reasoners that use a common data format. Also, this tends to be facilitated by the data bus that provides an efficient means by which information may be transferred between different reasoners.

It should be noted that certain of the process steps depicted in the flowchart of Figure 4 and described above may be omitted or such process steps may be performed in differing order to that presented above and shown in Figure 4. Furthermore, although all the process steps have, for convenience and ease of understanding, been depicted as discrete temporally-sequential steps, nevertheless some of the process steps may in fact be performed simultaneously or at least overlapping to some extent temporally.

In the above embodiments, data is downloaded onto the portable maintenance aid by connecting the portable maintenance aid to a system of the aircraft and downloading data from that system onto the portable maintenance aid. However, in other embodiments, data may be downloaded from the aircraft
in a different way. For example, data may be transmitted from the aircraft and received by the portable maintenance aid (e.g. via a wireless or wired connection, e.g. via a computer network e.g. via the Internet).

In the above embodiments, diagnosis of faults comprises performing the fault diagnosis operation described in more detail in WO2009/136183 "Assisting Failure Diagnosis in a System". However, in other embodiments, a different fault diagnosis process may be used, for example a neural network or fuzzy logic based diagnosis process may be used. Also for example, in other embodiments, diagnosis of faults comprises performing the fault diagnosis operation described in more detail in WO2009/077776 "Assisting Fault Mode and Effects Analysis of a System Comprising a Plurality of Components" which is incorporated herein by reference. Also for example, in other embodiments, diagnosis of faults comprises performing the fault diagnosis operation described in more detail in WO2010/038063 "Assisting With Updating a Model for Diagnosing faults in a System" which is incorporated herein by reference.

In some embodiments, in addition to a fault diagnosis operation, one or more of the reasoners are configured to perform a fault prognosis operation using data acquired from the aircraft to determine a likelihood of a fault occurring at some future time.

In the above embodiments, the method of performing aircraft maintenance (described in more detail earlier above with reference to Figure 3) is implemented using the portable maintenance aid (described earlier above with reference to Figure 2). However, in other embodiments a different type of device may be used instead of or in addition to the portable maintenance aid. Also, in other embodiments, more than one device, e.g. more than one portable maintenance aid, may be used and data may be shared between those devices.

In the above embodiments, the maintenance process of Figure 3 is performed (using the above described portable maintenance aid) on the aircraft. However, in other embodiments the maintenance process described above may be performed on a different vehicle, e.g. a land-based vehicle or marine vehicle. In other embodiments the maintenance process described above may be
performed on a different type of system, e.g. a non-vehicle system or equipment.

In the above embodiments, maintenance process of Figure 3 is performed to diagnose faults in one or more aircraft systems. However, in other embodiments, the maintenance process may be used to provide an indication of the "health" of one or more aircraft system. In other words, as opposed to providing a diagnosis of a system fault, indication as to the state or condition of that system may be provided. Thus, the above described systems and method may be used in a Condition Monitoring (i.e. Health Assessment) process. The terminology "Condition Monitoring process" is used herein to refer to a process comprising the acquisition of information and data that indicates the state of a machine/system over time.

In the above embodiments, each of the reasoner modules is located on the portable maintenance aid. Thus, the fault diagnosis operations are performed on the portable maintenance aid. However, in other embodiments, one or more of the reasoners is located remotely from the portable maintenance aid (e.g. onboard the aircraft). In some embodiments, one or more of the fault diagnosis operations is performed at a location that is remote from the portable maintenance aid (e.g. onboard the aircraft). In some embodiments, one or more of the fault diagnosis operations is a distributed process performed by a plurality of processors located at different locations. Also, in some embodiments, some or all of the information that is stored by the memory of the portable maintenance aid in the above embodiments is stored by a different entity that may be remote from the portable maintenance aid.
CLAIMS

1. A method of identifying faults in a vehicle (2), the vehicle (2) comprising a plurality of vehicle subsystems (4-12), the method comprising:

   for each vehicle subsystem (4-12):
   - receiving, by a respective subsystem reasoner (30-38) corresponding to that vehicle subsystem (4-12), information from that vehicle subsystem (4-12); and
   - using the information received from that vehicle subsystem (4-12), performing, by the respective subsystem reasoner (30-38) corresponding to that vehicle subsystem (4-12), a fault diagnosis process to determine, for each of one or more subsystem faults, a probability that that subsystem fault has occurred, each of the one or more subsystem faults being a fault the symptoms of which manifest in that vehicle subsystem (4-12);

   receiving, by a vehicle health reasoner (40), information from at least two different sources, the at least two different sources being selected from the group of sources consisting of each of the vehicle subsystems (4-12) and each of the subsystem reasoners (30-38);

   using the information received from the at least two different sources, performing, by the vehicle health reasoner (40), a further fault diagnosis process to determine, for each of one or more further faults, a probability that that further fault has occurred, each of the one or more further faults being a fault the symptoms of which manifest in more than one of the vehicle subsystems (4-12); and

   displaying, on a display (24), at least an identity of the subsystem fault or further fault that corresponds to the highest probability.

2. A method according to claims 1, the method further comprising:

   for each vehicle subsystem (4-12), prior to the subsystem reasoner (30-38) corresponding to that vehicle subsystem (4-12) performing the fault
diagnosis process, converting the information received from that vehicle subsystem (4-12) into a common data format or standard.

3. A method according to claim 2, wherein the information received by the vehicle health reasoner (40) is in the common data format or standard.

4. A method according to claim 2 or 3, wherein the common data format or standard is the MIMOSA(TM) Open Systems Architecture for Condition-Based Maintenance open data standard.

5. A method according to and of claims 1 to 4, wherein the subsystem reasoners (30-38) and the vehicle health reasoner (40) are connected together by a data bus (42) for passing information between the subsystem reasoners (30-38) and the vehicle health reasoner (40).

6. A method according to any of claims 1 to 5, wherein:
   - the vehicle (2) is an aircraft; and
   - the vehicle subsystems (4-12) are aircraft subsystems selected from the group of aircraft subsystems consisting of: a propulsion system (4), mechanical systems (6), a power system (8), a fuel system (10), a flight management system (12), an environmental control system, a hydraulics system, and a radar system.

7. A method according to any of claims 1 to 6, the method further comprising:
   - identifying at least one test to be performed in order to refine one or more of the probability values; and
   - displaying, on the display (24), an indication of each identified test.
8. A method according to claim 7, the method further comprising updating one or more of the fault diagnosis processes using results of at least one identified test.

9. A method according to any of claims 1 to 8, the method further comprising:
   for at least the displayed subsystem fault or further fault, identifying one or more remedial actions to be performed, the remedial actions being such that, if the remedial actions were to be performed, that subsystem fault or further fault would be repaired; and
   displaying, on the display (24), an indication of each identified remedial action.

10. A method according to claim 9, wherein the method further comprises:
    for each identified remedial action, identifying a set of instructions for performing that remedial action; and
    displaying, on the display (24), each identified set of instructions; wherein
    displaying a set of instructions comprises displaying some or all of an integrated electronic technical manuals relating to one or more of the vehicle systems (4-12).

11. A method according to any of claims 1 to 10, wherein
    the subsystem reasoners and the vehicle health reasoner are located within a Portable Maintenance Aid (14); and
    the steps of receiving data from the vehicle subsystems (4-12) comprises, for each vehicle subsystem (4-12), connecting the Portable Maintenance Aid (14) to that vehicle subsystem (4-12) and downloading
information from that vehicle subsystem (4-12) on to the Portable Maintenance Aid (14).

12. A method according to any of claims 1 to 11, wherein each fault diagnosis processes comprises

providing a fault-symptom model (26) comprising a probabilistic Bayesian network; and

using the Bayesian network, performing Bayesian inference so as to determine a probability for one or more faults.

13. Apparatus for identifying faults in a vehicle (2), the vehicle (2) comprising a plurality of vehicle subsystems (4-12), the apparatus comprising:

a plurality of subsystem reasoners (30-38), each subsystem reasoner (30-38) being configured to:

receive, from a respective vehicle subsystem (4-12), information; and

using the information received by that subsystem reasoner (30-38), perform a fault diagnosis process to determine, for each of one or more subsystem faults, a probability that that subsystem fault has occurred, each of the one or more subsystem faults being a fault the symptoms of which manifest in the vehicle subsystem (4-12) from which that subsystem reasoner (30-38) received information;

a vehicle health reasoner (40) configured to:

receive information from at least two different sources, the at least two different sources being selected from the group of sources consisting of: each of the vehicle subsystems (4-12) and each of the subsystem reasoners (30-38); and

using the information received from the at least two different sources, perform a further fault diagnosis process to determine, for each
of one or more further faults, a probability that that further fault has occurred, each of the one or more further faults being a fault the symptoms of which manifest in more than one of the vehicle subsystems (4-12); and

a display (24) configured to display at least an identity of the subsystem fault or further fault that corresponds to the highest probability.

14. A computer program or plurality of computer programs arranged such that when executed by a computer system it/they cause the computer system to operate in accordance with the method of any of claims 1 to 12.

15. A machine readable storage medium storing a computer program or at least one of the plurality of computer programs according to claim 14.
INTERNATIONAL SEARCH REPORT

PCT/GB2013/051688

A. CLASSIFICATION OF SUBJECT MATTER

INV. G05B23/02

ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G05B

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Further documents are listed in the continuation of Box C. See patent family annex.

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