Abstract Title: Maintenance of brake system for aircraft

A method for maintaining the braking system of an aircraft involves recording signals indicative of the presence of faults in an aircraft braking system, excess wear of consumables used in the braking system, and conditions indicative of development of such faults/wear in said braking system, wherein said record is transferred to a ground based computer server which processes the recorded data to evaluate the condition of said braking system. The data may be transferred via a port connection when the aircraft is on the ground or by satellite when the aircraft is airborne. Ground based systems can then ensure that components/spare parts required are provisioned at appropriate locations/airports so that personnel can carry out maintenance work without delays.

Apparatus for executing the above method is also disclosed.
Figure 1
Figure 2
AIRCRAFT BRAKE MONITORING

This invention relates to aircraft, in particular braking systems for aircraft.

According to one aspect of the invention, there is provided a method for maintaining the braking system of an aircraft, the method comprising:

- forming a record of signals indicative of the presence of faults in the system,
- excess wear of consumables used in the system, and conditions indicative of imminent or likely development of such faults and/or excess wear;
- transferring said record to a ground based computer server; and
- separately or within said server, processing data relating to said faults, excess wear and conditions and thereby evaluating the condition of said braking system.

According to a second aspect of the invention, there is provided apparatus for maintaining a record of signals indicative of the presence of faults in the system, excess wear of consumables used in the system, and conditions indicative of imminent or likely development of such faults and/or excess wear; and for transferring said record to a ground base computer server; and separate or within said server, data processing means for processing data relating to said faults, excess wear, and said conditions and for thereby evaluating the conditions of said braking system.

For a better understanding of the invention, reference will now be made by example to the accompanying drawings, in which Figures 1 and 2 are respective flow charts for an aircraft product support system and a product support system incorporating brake health management.
The process flow chart of Figure 1 shows how an example of how an aircraft Product Support System (PSS) can be integrated with a Brake Health Monitoring system and Brake Health Management to provide an integrated supply chain in which logistics and inventory management ensure the required components are available when required at the right location.

Aircraft equipped with the Brake Health Monitoring System will monitor signals representative of the operation of the braking system and record such signals when required. The signals, particularly those representative of brake outputs can be compared against expected outputs for a known set of monitored brake inputs. Signals representative of brake outputs include but are not limited to brake torque, temperature and vibration. Signals representative of brake inputs include but are not limited to brake pressure, brake current for electrically actuated brakes, actuator position, heat pack mass, wheel speed and aircraft mass. Any variation between measured output and expected output for a given set of inputs can be representative of wear condition and or faults within a brake assembly, for example a low value for brake torque and brake temperature accompanied by a change in the dynamic characteristics of the brake could be representative of broken drive regions on one or more discs.

The Brake Health Monitoring System could be a stand-alone system associated only with the brake and brake control system. Alternatively, the Brake Health Monitoring system could be part of or interfaced with a larger aircraft health management system. The Brake Health Monitoring System also needs to incorporate or interface with a Brake Health Management capability by processing monitored signals to determine brake health.
Data from the Brake Health Monitoring System on the aircraft can be transferred by a suitable link to a ground based server. The link could be a physical connection to download data at some convenient time when the aircraft is on the ground or preferably it could be a wireless link for download data on a real time basis during operation of the aircraft.

Brake Health Monitoring System data representative of sensor signals can then be processed to evaluate brake condition, in particular to determine the wear state of the brake and/or any existing, potential or imminent faults in the brake. The evaluation of brake condition can be carried out by, for example, the brake supplier, the aircraft constructor, the aircraft operator or a third party maintenance provider. Alternatively, this assessment of brake condition can be carried out within the Aircraft Health Monitoring System and the data representing this assessment can be transferred to the ground based server.

Once an assessment of brake wear and/or brake faults has been carried out, either on the ground or on the aircraft, action can be triggered to plan, schedule and provide spares and satisfy maintenance requirements.

Brake wear can include the wear of any consumables in the brake, such as the heat stack, or any other parts in the brake that are subject to wear during their service life. By monitoring brake wear a prediction of remaining brake heat stack life and other wearable component life can be carried out. This prediction of remaining life can then be used to determine when maintenance will be required using knowledge of the scheduled aircraft utilisation. By monitoring the wear condition and remaining life of the brakes on an aircraft it is possible to provision spare parts by ordering new heat stacks of brake discs when the lead-time for supply coincides with the remaining life. Use of
the PSS can provide a more integrated supply chain through the provision of information regarding what components will be needed, where and when they will be needed to all stakeholders within the supply chain. As a further step, thus system can be integrated with inventory management, logistics and manufacturing processes to ensure optimal and timely service provision of maintenance requirements.

In the interests of operational efficiency it is prudent to build in a safety factor for provisioning components, especially where long lead-time items are involved such as carbon-carbon brake discs.

Replacement brake heat stacks and other wearable components will be available at an appropriate time to coincide with maintenance action at a maintenance, repair and overhaul (MRO) facility. The supply of spare discs can preferable be handled through an inventory management system. The Inventory Management System can preferably track the availability of spare parts at a number of storage sites around the globe and move parts between locations so they can be provided from the most convenient location to meet the aircraft maintenance schedule.

If the health monitoring system indicates or predicts a fault or imminent fault in a brake then appropriate maintenance action can be planned around the aircraft operating schedule and any spare parts can be provisioned through the Inventory Management System to ensure the required parts are in the right place at the right time.

Corrective maintenance action can be carried out at a suitable MRO facility before the aircraft is returned to service with the operator. By provisioning spares parts and MRO activities around the aircraft operating schedule the disruption to the schedule and time the aircraft is out of service can be minimised.
Communication between the various parts of the process can be facilitated by utilising state of the art information technology including, but not limited to, satellite and Internet communication.

In order to further optimise maintenance routines it is desirable when a brake unit requires a new heat pack to be fitted to renew all brake heat packs to avoid the need to take the aircraft out of service on more than one occasion. However, to achieve this aim it is important to ensure that all the heat packs reach a, or close to a fully worn condition at the same time.

It is found that there is a spread of wear rates around the brakes on a aircraft so the brakes rarely reach a fully worn condition at the same time. GB 2,216,209 proposes a method and apparatus to disable less than all of the brakes on an aircraft during taxi operations when the wear rate of carbon-carbon friction discs has been found to be disproportionately high compared to the low energy levels that are involved.

By combining a system for disabling brakes during taxiing with a Brake Health Management System the wear of heat packs could be monitored and those heat packs with the most wear could be disabled during taxi operations. This would allow heat packs with the least wear to be used during taxiing, thereby increasing the wear of those heat packs until they were at the same wear state as the disabled heat packs.

The identity of heat stacks disabled on an aircraft would change over time as the wear state of the brake heat stacks changed, however, the overall aim of the system would be to balance the wear state of a predetermined number of heat stacks so they reached a fully worn condition and, therefore, a requirement for replacement at the
same time. The result is to minimise the number of times an aircraft only has to be
taken out of service once in order to renew brake heat stacks and/or optimise heat
stack replacements to coincide with scheduled maintenance events.

One non-limiting embodiment of a product support system incorporating Brake Health
management is shown as a system overview in Figure 2 in which the various elements
and lines of communication are depicted.

The product Support System compares apparent wear and failure rates to
expectations. Trend analysis will then predict a time window for component
replacement. Operator maintenance preferences, such as what, when and where to
service, can be taken into account and an optimal recommendation for maintenance
made. Any recommendations are made to maximise scheduled maintenance whilst
minimising the cost of early replacement and unscheduled maintenance. In addition
the capability to identify faults and brake condition electronically reduces the need for
time-consuming inspections.

The aircraft constructor maintains a Health Management System that can manage the
health of all health monitoring systems on an aircraft or, alternatively, just the brake
health monitoring system and collects data from the aircraft Brake Health Monitoring
System via a real time satellite link.

The aircraft wheel and brake manufacturer carries out the following functions:

- **Fault Detection** through diagnosis of messages supplied by Health
  Management System;
• **Wear Management** by monitoring wear rates for in-service components using messages received from Health Management System;

• **Product Performance** Improvement by monitoring wear and fault trends to support design improvement work;

• **Supply Chain Controller** governs the movement of components and materials within the supply chain;

• **Production Controller** to forecast demand for and initiate production of new components and assemblies;

• **Maintenance Planner** supplies maintenance recommendations to operators, taking into account their preferred maintenance practices;

• **OEM Manager** interfacing with and manage the relationship with the constructor;

The aircraft wheel and brake manufacturer needs to provide systems and infrastructure to underpin the above functions, such as data storage and reporting.

Aircraft operators will interface with the Product Support System to advice preferences for where maintenance should be carried out. The Product Support System can provide proposals to operators for opportunistic (unscheduled) maintenance to meet their preferred maintenance practices. The aircraft operators might have in-house
workshop facilities for providing maintenance or have relationships with third party MRO providers.

The Lead Logistics Provider will be responsible for logistics and inventory functions, interfacing with the aircraft wheel and brake manufacturer, MRO providers and operator workshops to provide parts at the required location and time.

The manufacturing function will preferably be part of the aircraft wheel and brake manufacturers organisation, although this could be a third party sub-contract facility. The manufacturing function will utilise a production management tool such as SAP through which suppliers would preferably be able to interface with the Product Support System.

The MRO facility will contain their own maintenance planning systems. They will send and receive information and components via the Lead Logistics Provider. Such MRO organisations could be part of the aircraft wheel and brake manufacturer, the operator or be independent. The product Support System will manage the interface between MRO facilities, operators and third parties.
CLAIMS

1. A method for maintaining the braking system of an aircraft, the method comprising:
   forming a record of signals indicative of the presence of faults in the system, excess wear of consumables used in the system, and conditions indicative of imminent or likely development of such faults and/or excess wear;
   transferring said record to a ground based computer server; and
   separately or within said server, processing data relating to said faults, excess wear and conditions and thereby evaluating the condition of said braking system.

2. Apparatus for maintaining a record of signals indicative of the presence of faults in the system, excess wear of consumables used in the system, and conditions indicative of imminent or likely development of such faults and/or excess wear; and for transferring said record to a ground base computer server; and separate or within said server, data processing means for processing data relating to said faults, excess wear, and said conditions and for thereby evaluating the conditions of said braking system.

3. A method and apparatus substantially as hereinbefore described with reference to the accompanying drawings
Documents Act 1977: Search Report under Section 17

<table>
<thead>
<tr>
<th>Category</th>
<th>Relevant to claims</th>
<th>Identity of document and passage or figure of particular relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>1, 2</td>
<td>WO02/12043 A1 (Dunlop); whole document; note especially disclosure of transferring data via data ports/satellite</td>
</tr>
<tr>
<td>X</td>
<td>1, 2</td>
<td>US2004/084252 A1 (Devlieg); whole document; see especially abstract</td>
</tr>
<tr>
<td>X</td>
<td>1, 2</td>
<td>US2003/102191 A1 (Devlieg); whole document; see especially abstract</td>
</tr>
<tr>
<td>X</td>
<td>1, 2</td>
<td>US6471015 B1 (Goodrich); indicates when brake discs need replacing</td>
</tr>
<tr>
<td>A</td>
<td>-</td>
<td>US5581464 A (Vorad); discloses a black box which records details accessible by a ground based computer</td>
</tr>
</tbody>
</table>

Categories:

| X | Document indicating lack of novelty or inventive step |
| Y | Document indicating lack of inventive step if combined with one or more other documents of same category |
| & | Member of the same patent family |
| A | Document indicating technological background and/or state of the art |
| P | Document published on or after the declared priority date but before the filing date of this invention |
| E | Patent document published on or after, but with priority date earlier than, the filing date of this application |

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC:

F2F

Worldwide search of patent documents classified in the following areas of the IPC:

B60T; B64C; B64F; F16D

The following online and other databases have been used in the preparation of this search report:

EPODOC, WPI