LANDING GEAR HEALTH MONITORING

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ABSTRACT

This paper examines the potential applications for a landing gear health monitoring system. It describes the operating principles of much of the landing gear equipment and discusses how health-monitoring applications could be implemented and how this might benefit aircraft and their operators.

The paper does not attempt to specify in detail each sensor, or the architecture needed to support those sensors, but it does discuss some of the operating parameters and some of the philosophies for successful operation.

The discussion in this paper is based upon a typical large civil aircraft in service today; it is not aircraft or landing gear specific. The paper's main aim is to provide an awareness of the many benefits of health monitoring when applied to landing gear.

1. HEALTH MONITORING

Health and Usage Monitoring Systems (HUMS) have now become well established for both large helicopters and aircraft gas turbine engines.

So what is aircraft Health and Usage Monitoring?

- Health Monitoring is a system used for monitoring the health of aircraft parts and/or systems. It may include prognosis, fault detection and identification, limit exceedance, in-flight damage, degradation and failure mitigation (life shortening)
- Usage Monitoring is a system used for monitoring the usage of aircraft parts and/or systems. It may include part identification, total life, life usage, modification status, asset management and maintenance activities

Helicopter vibration monitoring has been in use since the early 1970's, but it was not until 1991 that the first certified helicopter health-monitoring system was fitted to a North Sea oil rig operator's helicopter. Since then, this application, from only one HUMS company has accumulated more than 2 million flight hours across 20 aircraft types.

Typical helicopter applications have focussed on:

- Rotor track and balance
- Limit exceedance monitoring
- Rotor, engine, transmission, and gearbox health monitoring
- Structures usage monitoring
- Structures health monitoring

Another successful area for HUMS has been with gas turbine engines. Engine condition monitoring also started to appear in the 1970's with simple data recording systems and limited vibration analysis capabilities.

Today's engine health monitoring systems have complex data comparison and trending capabilities and need to have high integrity with near real-time operation.

Typical gas turbine engine applications have focussed on:

- Fan balance data
- Gas path analysis
- Fuel flow
- Vibration
- Oil properties
- Performance monitoring

The next generation of engine health monitoring systems are planned to have advanced computing systems designed to solve difficult pattern recognition, diagnostic and forecasting problems. They will also incorporate asset management capabilities.

2. LANDING GEAR

Landing Gears (figure 1) are commonly recognised as "the essential intermediary between the aeroplane and catastrophe" and are expected to work without failure. Due to the need to routinely replace worn tyres and brakes they are also an area of high maintenance activity. As such, landing gears have one of the highest costs for direct maintenance on civil aircraft today.

Landing gears have to live in a harsh environment. They have to operate reliably in an environment where temperatures can range from -55C to +80C, including wet, snowy, ice and slush conditions. They are open to attack from contaminants such as runway de-icers. They can be subjected to high vertical rates of descent (hard landings), which can transmit high loads into the landing gears and connecting structures. They may also be subjected to in-service incidents such as runway departures and collisions during taxiing.

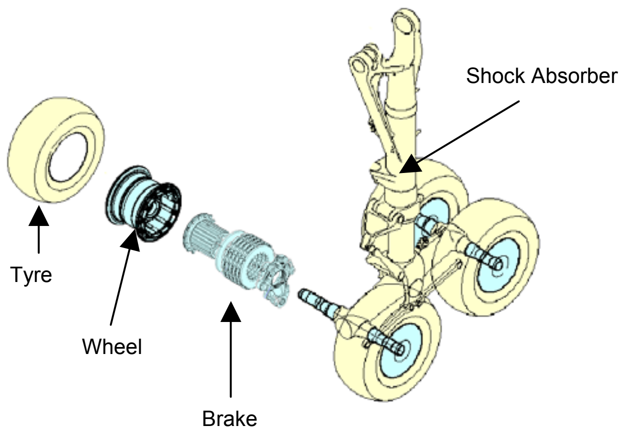

Figure 1 - Typical 4-Wheel Main Landing Gear

Tyres and brakes are expendable items with high associated costs of ownership; due to this fact there is continual pressure from customers to reduce these costs by whatever means.

It is clear that engines and large helicopters have benefited from the introduction of fairly complex health-monitoring systems but what possible benefit could you gain from monitoring the health of a landing gear?

3. BRAKE WEAR

The first carbon brake went into airline service in 1973 with the Super VC 10 aircraft. Carbon brakes are substantially lighter than steel brakes and they have higher energy absorption characteristics that do not fade at higher temperatures. Carbon aircraft brakes are constructed by sandwiching together numerous discs of carbon (see figure 2). A carbon brake may achieve as many as 2500 landings between overhauls; dependant on design and operating conditions.

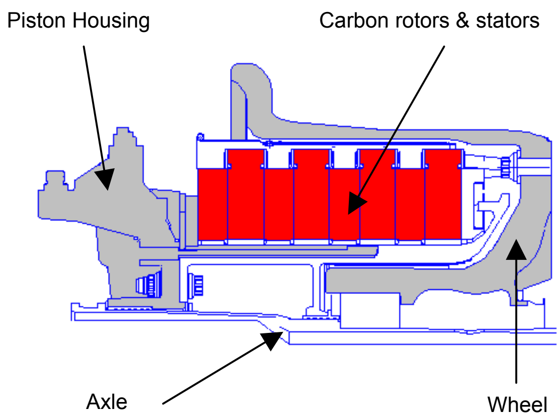

Figure 2 – Cross section of a typical aircraft brake

Brake wear is currently detected using a pin that is attached to the pressure plate (inner carbon disc - see figure 3).

The rigid brake pin is attached to and moves with the wearing carbon until the pin becomes flush with the guide in the piston housing body. At this point the brake needs to be changed. One problem with this measurement system is that the interpretation of “flush” can be ambiguous.

Figure 3 – A typical brake wear pin

The amount of wear during one flight cycle for a whole carbon brake is very small and is in the region of 0.001” (0.025mm). To overcome the need to manually check the brake wear pin, an automatic measuring system could be installed. A simple solution could be to replace the wear pin with a high precision linear actuator.

Providing a prediction as to when the brake will reach the end of its life is a difficult problem; carbon temperature, braking power applied, engine idle thrust, runway conditions, taxi time and humidity can all affect the rate of brake wear.

The use of pattern-recognition techniques combined with a wear model could be one way to accurately predict the remaining life of a brake (see figure 4).

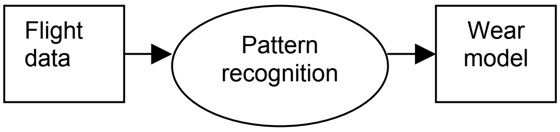

Figure 4 – Brake wear prediction model

To make this model work there are 3 main parameters that need to be fed into the model:

1. Brake energy
2. Brake temperature
3. Brake wear state (heat-pack mass)

The amount of energy absorbed into the carbon during braking is a function of aircraft mass and aircraft velocity. The energy can be calculated by capturing certain aircraft parameters such as:

1. Wheel landing velocity
2. Wheel taxi velocity
3. Aircraft mass
4. Position of flying control surfaces

Alternatively, a brake torque sensor could be utilised (see brake torque section).

Brake temperature is an important factor as the rate of carbon brake wear is affected by temperature. Brake temperature is already a parameter that is monitored in civil aircraft today (see brake temperature section).

With the brake wear state (heat-pack mass), energy absorbed and brake temperature known and recorded, an accurate brake wear model can be created.

The potential benefits of such a brake wear monitoring and prediction system could be to:

1. Predict brake replacement and enable better maintenance planning
2. Provide maintenance crews with remote brake wear data, without need to physically check each individual brake
3. Eliminate brake wear pin length ambiguity
4. Ensure brake has adequate life for planned flights
5. Improve fault diagnosis
6. Reduce maintenance costs and time
7. Provide accurate usage monitoring

4. BRAKE TEMPERATURE

Brake temperature can have a large effect on carbon brake wear. At low brake temperatures with associated low energy braking (such as taxiing) powdery wear debris is formed at the brake disc interfaces. This debris of worn matrix particles causes abrasive wear, which is the most damaging mode in terms of brake wear. At higher brake temperatures, with associated high-energy braking (such as landing), a smooth friction film is formed which serves as a solid self-lubricant. This film will protect the brakes; therefore reducing the effects of brake wear. At very high temperatures, brake carbon will start to decompose in a process known as oxidation.

It is therefore important to know brake temperature and prevent them from overheating. For most large civil aircraft the brake temperature probe is located at the centre of the brake (see figure 5).

The brake temperature probe monitors the temperature of the brake to ensure that:

1. The pilot is aware of hot brakes (and can take the appropriate action)
2. The brakes are safe to be retracted into the landing gear bay

Should the brake temperature heat the wheel and tyre to a point where there is risk of tyre burst or wheel rim release, a eutectic plug in the wheel will automatically release the gas pressure and deflate the tyre.

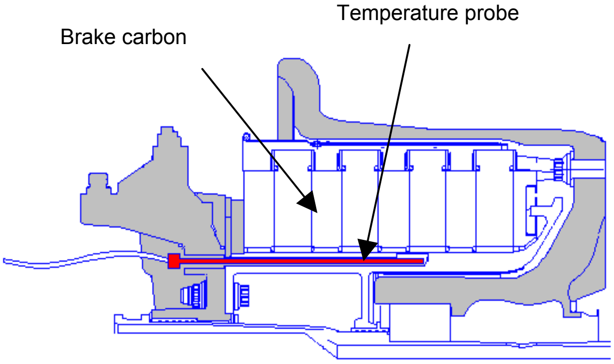

Figure 5 – Brake temperature probe location

As the temperature probe is not in direct contact with the brake carbon there is a small gap between probe tip and the hot carbon. The time taken for the heat to soak through the carbon and radiate across this gap produces a time delay between the actual carbon temperature and the monitored temperature.

A number of functions within any landing gear health monitoring system will require an accurate and fast temperature input.

Relocation of the temperature probe to a position within the carbon would be the optimum location, but a number of additional problems result from imbedding the sensor into the carbon:

1. Securely attaching the sensor into the carbon
2. High temperatures affecting sensor electronics/materials
3. Probe position affecting assembly/disassembly of the brake
4. Heat-pack movement due to wear

5. TYRE PRESSURE

Tyre pressure is another parameter that is monitored in large civil aircraft today. It is important to keep tyres inflated to their correct pressure. Under-inflated tyres can creep or slip on the wheel rim or suffer from excessive shoulder wear. In more severe cases they can suffer crushed sidewalls or in dual-tyre applications can leave other wheels carrying a disproportionate load. Over inflated tyres are susceptible to bruising, cuts and shock damage; ride quality and traction may be reduced. Continuous high-pressure operation can result in tyre centre wear and reduced landings performance.

Traditionally, tyres are checked manually at the valve with a pressure gauge. Before the check is made they have to be left to cool for 3 hours to ensure the gas and tyre temperatures have equalised. Most aircraft today also have automated tyre pressure detection systems. A typical system would have the pressure sensor fitted to a tapping in the wheel (see Figure 6).

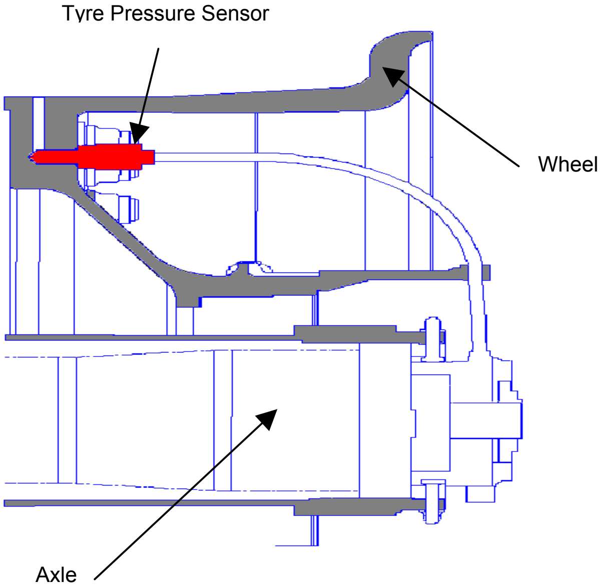

Figure 6 – Typical tyre Pressure Sensor Installation

Tyre temperature will increase due to the tyres working, brake temperature increases or ambient temperature changes. Historically, no tyre pressure detection systems have compensated for gas temperature. New systems are now emerging (some already in-service) that have tyre gas temperature compensation.

With both the tyre pressure and tyre gas temperature known, the tyre pressure detection system can output the corrected tyre pressure irrespective of tyre temperature.

Other tyre pressure systems are being developed that have the pressure and temperature sensors embedded into the tyre sidewall. Hand-held readers are being proposed that utilise Radio-Frequency IDentification (RFID) technology. The ability of RFID to store data has the added advantage that the tyre's history can be stored on the chip.

Wireless links are utilised to make connections from wheels to axles across very small air gaps. The use of longer range wireless links have been proposed but issues with interference and regional wireless regulations will need to be overcome before they are freely adopted for aircraft use.

Systems are available for large commercial vehicles that automatically detect and correct tyre pressure. These systems are unlikely to be adopted for passenger aircraft however, as the weight of installing nitrogen charging and storage equipment would be prohibitive.

The potential benefits of a temperature-compensated tyre pressure monitoring systems include:

1. Accurate pressure measurement automatically compensated for temperature changes
2. Instant tyre pressure correction information
3. Elimination of manual tyre pressure checks
4. Provides tyre history

6. BRAKE TORQUE

There are two reasons why there could be a need to monitor brake torque:

1. Feedback of braking effort into the braking control system
2. Identify the amount of energy absorbed by the brake

For landing gear health-monitoring systems the amount of energy absorbed by the brake is an important parameter. Combined with brake wear state and brake temperature, it provides a means of monitoring brake health and enables a number of brake-temperature related functions which will be covered later in this paper.

The location of the torque sensor will be critical to the effective operation of the system. The following components would be suitable for the embodiment of a torque sensor (see figure 7):

1. Torque pins
2. Brake torque rods
3. Brake torque tube

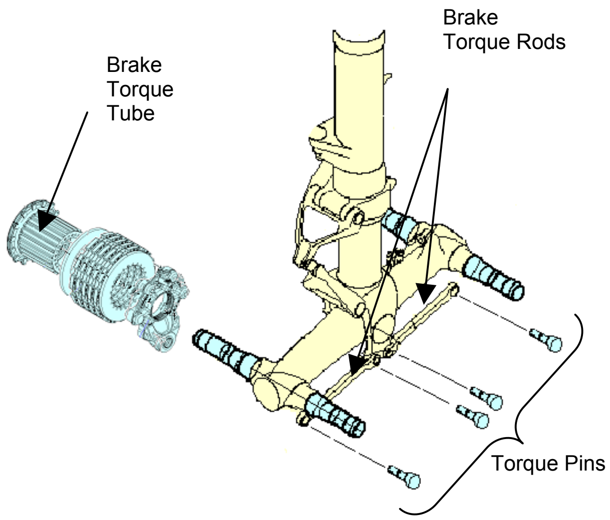

Figure 7 – Potential Brake Sensor Locations

The type of sensor will also need to be considered. Strain gauges are a familiar solution to many load measurement applications and have already been used to instrument flight-test aircraft brake torque pins. There are, however, some concerns as to their accuracy after long periods of installation, especially in aggressive environments. Today's aircraft manufacturers are looking for sensors that will be fitted for the life of the component without adjustment or recalibration.

Developments with embedded fibres (optical or conventional conductors) may make it possible to develop strain sensors that are permanently embedded into existing components. This is still a relatively new technology and will require development, but has the potential benefits of accuracy with unlimited life.

Wheel dynamometers are used in the automotive industry to test vehicles and can be used to measure torque and braking force. They typically utilise Piezo shear sensors fitted to special-fit wheel hubs. As the wheel hubs on most aircraft brakes do not transfer torque, another location such as the torque tube would need to be chosen. This technology needs to be further investigated for possible applications.

With the availability of an integrated torque sensor at each brake position, brake torque values can be provided to both the health monitoring system and the braking control system (see figure 15).

The potential benefits of a brake torque sensing system would be:

1. Allow measurement of brake energy.
2. Allow additional set of monitoring systems to be used:
    - Brake wear
    - Brake removal prediction
    - Automatic brake cooling
    - Brake fault diagnosis
    - Predictive turn-around time
3. Compensate for brake gain variation

7. WHEEL SPEED

Wheel speed is an essential input into an aircraft's braking-control and anti-skid systems. To detect the wheel speed, each wheel is fitted with a tachometer in the wheel hub/axle interface. Today's wheel speed tachometers are generally based around variable reluctance technology and are relatively inaccurate at low speeds. Although the braking control system can compensate for this effect, it is intended that future speed sensors will have improved accuracy at low speed.

Within a landing gear health monitoring system, wheel speed can be used as one of the essential inputs required to calculate brake energy. The sensor will need to detect landing and the slower taxi velocities. The health monitoring system will also need to be aware of wheels that have stopped rotating; possibly assisting other sensors in determining a wheel or brake failure.

8. VIBRATION

Vibration in aircraft landing gear is not a significant problem due to rigorous processes for design and testing. Components are carefully designed to avoid resonant frequencies and wheels and tyres are balanced to ensure smooth running. Vibration is normally excited by braking and is exacerbated by worn or damaged landing gear components.

Severe vibration such as shimmy or gear walk can cause structural damage but most incidences of vibration are usually low amplitude and can be attributed to:

- Wheel imbalance
- Bearing defects
- Tyre damage and imbalance
- Brake faults

In-service bearing failures can occur prematurely due to incorrect assembly or contaminated lubricants. Bearing failures are usually preceded by an increase in bearing vibration and so condition monitoring could be used to detect degrading bearings before they catastrophically fail.

Damage to tyres (flat spotting and tread damage) will alter the balance of the wheel and tyre. Damage to wheel rims and the loss of the wheel tie-bolts (connecting two halves of the wheel rim) will also take the wheel out of balance.

Any failing component within a system will have a unique vibration signature. The monitoring system will be programmed to recognised these unique signals and then upon occurrence, identify the fault.

The potential benefits of vibration monitoring would be:

1. Early detection of landing gear faults
2. Ability to plan removals

9. AUTOMATIC BRAKE COOLING FANS

Brake cooling fans are an optional fit on most large civil aircraft. They are usually fitted by airlines that operate from hot/high airfields or where the time to turn the aircraft around for its next flight is critical. When fitted, they are normally controlled by a manual switch in the cockpit. Switching the brake cooling fans on (and off) is at the discretion of the flight crew.

The brake cooling fans and their motors fit into the external part of braked wheels and the axles (see figure 12). When the fans are operating air is drawn into the brake around the piston housing, across the heat-pack, through the wheel spokes, through the fan impeller and back out to atmosphere.

With the introduction of more efficient airport services (fuel, baggage, passenger handling) aircraft turn around time will be reduced. A future operational constraint may be the time taken for brakes to cool following a landing and taxi to the stand.

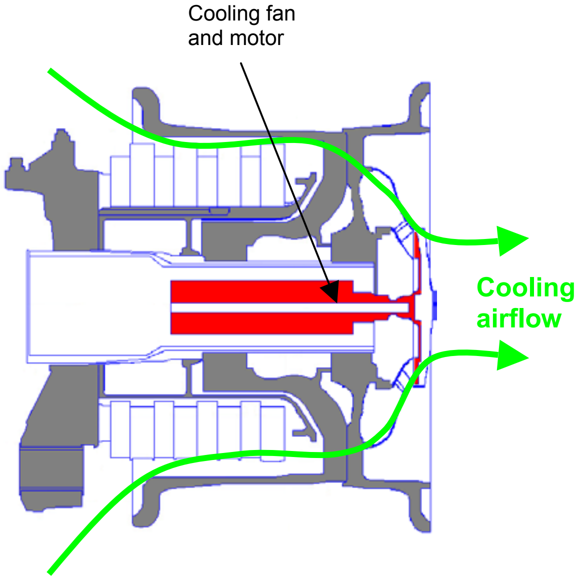

Figure 12 – Brake Cooling Fan Installation

One of the benefits of having new, or more capable, sensors fitted to the landing gear is that additional functions can be introduced. One such function would be the automation of brake cooling fans. The fans could be automatically switched on when the brakes reach a pre-defined temperature. Once sufficient cooling of the brakes has taken place the fans could be automatically switched off.

Automatic cooling of the brakes will require the cooling fans to be switched on and off at pre-determined temperatures. There are a number of factors that affect these pre-determined points:

1. Rate of temperature rise (how fast the brakes are heating up)
2. The risk of inducing increased wear to the carbon

If the brakes are heating up rapidly the cooling fans should be switched on as early as possible to arrest the rise to high temperatures. However, switching the fans on too early, when the carbon is still cold, may delay the formation of the smooth friction film that is trying to form and thus accelerate wear.

Therefore, the 3 parameters that need to be known and monitored to control efficiently the brake cooling fans are:

1. Brake wear (heat-pack mass)
2. Brake energy (torque or aircraft configuration)
3. Brake temperature

The potential benefits of automated brake cooling fans are:

1. Reduction in pilot workload
2. More efficient cooling of brakes
3. Reduced turn-around times

10. BRAKE COOLING TIME PREDICTION

Due to safety considerations, there is an upper temperature limit above which hot brakes should not be retracted into an aircraft landing gear bay. Aircraft normally wait an appropriate amount of time at the aircraft gate to ensure that their brakes are cool enough to taxi to the end of the runway and then take off directly.

There are no aircraft systems that make this calculation; it is usually made by the flight crew using basic calculations or experience. The problem is that these estimations are not particularly accurate and can lead to an aircraft missing its take-off slot with brakes that have not adequately cooled.

Brake cooling-time prediction requires the same input parameters as brake wear prediction and automatic brake cooling fans: brake wear (heat-pack mass), brake energy (torque) and brake temperature. It also requires additional inputs that will affect the cooling rate such as:

1. Ambient temperature
2. Wind speed & direction
3. Whether brake-cooling fans are fitted or not

The system will continually calculate the amount of energy absorbed by the brake. At the same time it will also estimate the cooling rate taking into account the heat-pack mass and the outside air conditions. Once braking has ceased, the system will then be able to predict the time it will take for the brakes to cool to a pre-determined level.

The potential benefits of a system to predict brake-cooling times are:

1. Accurate prediction of brake-cooling time
2. Provision of cooling time information to flight/maintenance crews

11. SHOCK ABSORBER MONITORING

Landing gear shock absorbers are primarily fitted to absorb the impact on landing and protect the aircraft structure; they also provide improved ride comfort during taxiing. Shock absorbers are normally located in the main fitting of each landing gear (see figure 1).

Shock absorbers have a very simple method of operation; it absorbs energy by first forcing a chamber of oil against a chamber of nitrogen which compresses the gas. During the compression process, the oil and gas either remain separated or are mixed depending on the type of design. After the initial impact, the gas pressure forces the oil back into its chamber through recoil orifices. Many designs have a metering pin extending through it, and by varying the pin diameter the orifice area is varied providing constant strut load.

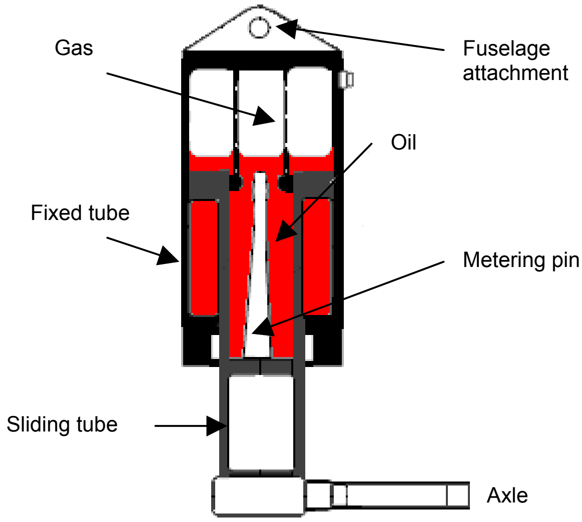

Figure 13 – A Typical Telescopic Landing Gear Shock Absorber

To ensure that shock absorbers operate at their optimum performance the correct ratio of gas pressure and oil level must be maintained within each unit. This is particularly important for aircraft with multiple main landing gears, as each landing gear has to equally share the landing loads.

Checking and re-establishment of shock absorber gas and oil levels is a time-consuming maintenance operation. The check is carried out by comparing the shock absorber extension against its internal gas pressure. With the inclusion of sensors that can monitor the fluid, gas and the relative extension; the need to physically check shock absorber levels and extensions could be eliminated.

Benefits:

1. Shock absorber monitoring will eliminate the need for lengthy procedures to check the gas pressure and shock absorber extension
2. The condition of the gas and oil seals may be monitored

12. STRUCTURAL HEALTH MONITORING

Landing gears are designed to withstand high structural loads that are associated with landing and taxiing. They are also designed to withstand the most severe braking activity such as a rejected take off. Landing gears may have a life of up to 60,000 landings. However, should the landing gear be inadvertently operated outside of its fatigue design usage, this may accelerate fatigue.

Attaching a network of strain detection devices onto the landing gear or its supporting structure could enable the health monitoring system to record the strains that the gear has been subjected to. The recorded data could then be used to build up a history of the usage that the landing gear has been subjected to. This data could then be used to:

- Assess landing gear structural health.
- Provide landing gear usage data.
- Indicate any abnormal events.

13. ABNORMAL EVENT MONITORING

Occasionally, landing gears are subjected to loads caused by a number of unusual and extreme operating conditions. One of the more widely recognised of these is when the aircraft lands with a high vertical rate of descent at touch-down. These events are called “hard” landings and are normally due to difficult landing conditions caused by severe weather conditions and/or loss of lift. Very hard landings may cause damage to both landing gears and their supporting aircraft structures. Following a report of a hard landing by the pilot the subsequent inspection can involve extensive checks of the landing gear and supporting aircraft structure. These checks are very time-consuming and normally involve inspections for damage and distortion due to impact and high loads. The airframe and Landing Gear manufacturers are often called upon to provide support to return the aircraft to service.

The ability to detect the exact magnitude of a load (especially hard landings) would take away any ambiguity over the loads that the landing gear has been subjected to. Recording and processing both the outputs from the structural health and the shock absorber monitoring systems could achieve this. A further benefit from any data gathered could be the ability to target areas for inspection, thus reducing the time to return the aircraft to service.

The potential benefits of monitoring for abnormal events are:

1. Accurate detection of the event.
2. Targeted post-event inspection criteria.

14. SENSORS

This paper introduces a number of new sensors that will be used exclusively for health monitoring. There are also sensors already fitted to landing gear that provide essential data to aircraft control systems. Although these essential system sensors may require updating for health monitoring purposes, their primary functions will continue. The introduction of a health monitoring system utilising existing sensors should not in any way affect the operation of the existing systems.

A matrix of proposed and existing landing gear sensors and their functions is shown in figure 14.

Function	Sensors				
	Brake temp	Torque	Brake mass (Wear state)	Tyre press	Tyre temp
Predict brake wear	✓	✓	✓		
Predict brake cooling time	✓	✓	✓		
Auto brake cooling fans	✓	✓	✓		
Tyre press.				✓	✓
Brake temp.	✓				
Torque		✓			

Function	Sensors				
	Shock absorber press + temp	Wheel Speed	Vibration	Shock absorber extension	Structural devices (strain)
Shock absorber monitoring	✓			✓	
Abnormal events	✓			✓	✓
Structural health					✓
Wheel speed		✓			
Vibration			✓		

Figure 14 – Proposed and Existing Landing Gear Sensors

15. AIRCRAFT & GROUND INTERFACES

All outputs from health monitoring sensors need to be conditioned and then stored on the aircraft until such time as it can be downloaded. The amount of data stored will depend on the sampling rate and number of sensors. A small amount of the sensor output may need to be processed for on-aircraft use; the majority will need to be downloaded to a ground network for storage and processing. Today there are a number of established systems used to transfer data from the aircraft to the ground:

- ACARS (Aircraft Communication Addressing and Reporting System)(VHF)
- Satcom
- HF Datalink
- Gatelink (UHF)

ACARS, Satcom and HF are all long-range data-links that may have restrictions (and a high cost) on the amount of data that can be downloaded for health monitoring purposes. Gatelink is suitable for large downloads but is short-range and can only be used after the aircraft has landed. The problem with short-range transfer systems is that they reduce the amount of time available to analyse the data during a short aircraft turn around.

One of the most beneficial parts of a health and usage monitoring system will be its ability to utilise ground networks to store, compare, process and distribute information. The data will be available via the ground network to a series of operator computer terminals. For aircraft health monitoring the computer terminals can be used to provide:

- Operator fleet knowledge
- Aircraft maintenance planning
- Performance monitoring/trending
- Component prognosis
- Component diagnosis

16. INTEGRATION

There are two types of integration that need to be considered for health monitoring systems:

1. Vertical
2. Horizontal

Vertical integration is the flow of data from the sensor up through signal conditioning devices, data buses; comparison devices and then into the processing unit.

Horizontal integration is the flow of data across each health-monitoring function. Prognosis and diagnosis will benefit greatly from horizontal integration. For example: if one brake is indicating an elevated temperature this may not in itself prove that the brake is faulty; it could be a temperature sensor fault or just that this brake is working harder than the others; however, if this elevated temperature is combined with increased wear and vibration this could confirm that this brake is faulty. With improved multiple sensor information the system may even be able to pin-point the exact fault.

17. MAINTENANCE PLANNING

One potential benefit of a health-monitoring system is its ability to identify faults and then assess the faults' severity. The continuous assessment of a fault by the health monitoring system will enable operators to better plan when aircraft can be taken out of service for replacement or repair.

With fully integrated health-monitoring systems, the requirement to remove components at a pre-determined life can be reduced. The aircraft operator will be able to assess the components health and then plan the optimum time for removal. For components that have shown signs of degradation these components can be removed well before failure occurs. For components that are operating without fault, it is expected that their lives would be extended.

Aircraft operators will be able to have more control over the timing of component removal and replacement. This will move more components onto condition-based maintenance.

The potential maintenance benefits are:

1. Elimination of unnecessary inspections and removals
2. Decreasing scheduled and unscheduled maintenance
3. Early detection of problems, reducing repair costs
4. Longer part use with fewer manual inspections
5. Maximizing the installed life of mechanical and electronic components
6. Decreased down-time

18. USAGE MONITORING

For components that have a pre-determined life, of are structurally significant items, usage monitoring can provide benefits. The system must first of all be able to recognise the component and identify its expended life (if any) and its modification standard. This can be achieved through pin programming (additional channel in electrical plug connector to identify component) or through new RFID techniques. The usage monitoring system having been able to identify the new component will then begin to track its usage and will be able to keep a record of landings, retractions or even brake utilisations. If you then combine this usage data with the health monitoring data, this will then build up a detailed picture of the components life, and what type of operating regime it has been subjected to whilst fitted to the aircraft.

Usage monitoring can also be used to locate and track components in a supply chain. It can help reduce the movement of parts ensuring that parts are ordered in good time and are in the right place at the right time. It can provide the history of a part for statistical, fault diagnosis and servicing reasons. It can also help in asset tracking and configuration control.

19. CONCLUSION

Health monitoring has been successfully deployed in large helicopters and gas turbine engines and although landing gears are not as complex, many of the principals and techniques are equally applicable.

Many of the functions and sensors discussed in this paper are only concepts and will require many hours of design, testing and integration before making it onto an in-service aircraft. To get the maximum benefit from a health-monitoring system, a consolidated set of sensors must be chosen that will allow full functionality without added complexity, cost and weight. Operators will not want to spend time diagnosing faults in health-monitoring systems that are installed to reduce maintenance activities.

By combining the output from multiple sensors, individual faults can better be understood and diagnosed. By knowing all the operational loads and events that a landing gear has been subjected to, provides a detailed record that may support changes in the way that the aircraft is operated or lead to equipment design improvements.

To ensure that the data is readily available to aircraft operators a capable support network will need to be put in place. This network will have to take the downloaded data and then be able to quickly extract key information. The data will have to be displayed at the operators terminals and in sufficient time to for it to be useful to ground crews.

It is evident that there are a considerable number of health-monitoring applications that could be utilised for landing gears. Each new health monitoring function however, will have to justify its existence on economic, operational or safety grounds. They will also have to be carefully assessed to ensure that there is sufficient benefit to the aircraft owners and operators.

Overall the benefits of an integrated health monitoring systems should provide a landing gear with reduced maintenance inspections, longer component service, improved fault diagnosis, improved safety and increased aircraft availability.