Aircraft Landing Gear Fluid Level and Landing Energy Monitoring System

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ABSTRACT

Hard landing events and improper hydraulic fluid level within the landing gear shock strut have historically caused failures and aircraft mishaps and have been highlighted with recent aircraft incidents. This paper describes a structural health monitoring (SHM) system that will detect both hard landings and improper fluid level made possible by recent technical advances in programmable, digital, Commercial Off The Shelf (COTS) data recorders utilizing very simple, precise, active pressure measurements. The proposed system will alert maintainers/operators to a potentially dangerous aircraft condition that can be addressed before leading to component failure and aircraft mishap. Recent field-testing of operational landing gear struts has revealed that the pressure measurements are sufficiently accurate to determine when a landing gear shock strut is improperly serviced to the correct hydraulic fluid level.

INTRODUCTION

As with all aircraft, the landing gear system is a non-redundant, flight safety critical sub-system. In operational use, the landing gear system is a frequent source of mishaps. Many aircraft have experienced mishaps that are out of proportion when compared to other aircraft systems. Primary areas of concern and failures relate to hard landing events and maintaining the proper hydraulic fluid level within the shock strut. These two concerns have historically caused failures & aircraft mishaps and have been highlighted with recent aircraft incidents. Aircraft have experienced mishaps caused by hard landings, and/or improper landing strut fluid level.

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This SHM system can be programmed to process landing gear strut internal pressures for events before and after the Weight On Wheels (WOW) indication signal. In-flight pressure data that varies from predetermined aircraft values will trigger a fault signal to a ruggedized display unit mounted in an easily visible location for a ground maintenance check. Similarly, pressures that exceed a predetermined aircraft value shortly after WOW indication can be programmed as a "Hard Landing" event, and trigger the fault display flag. This SHM system may be incorporated on any aircraft with the software modified as necessary for the aircraft's unique shock strut characteristics.

In furthering this technology, the capability exists to develop an onboard real-time monitoring system for different types of critical hydraulic damping systems. This system could be capable of interfacing with modern vehicle health monitoring/management systems; providing increased pilot awareness and reducing the maintenance burden on the fleet and operator.

FLUID LEVEL MONITORING AND HARD LANDING INDICATION SYSTEM

Aircraft, which are supported by telescopic oleo/pneumatic landing gear shock struts, have the weight of the aircraft supported by multiple pockets of compressed nitrogen gas. Accurately measuring main and nose landing gear strut gas pressures, with "pressure corrections" made for errors caused by landing gear seal friction, allows for the accurate measurement of the aircraft sprung weight. Aircraft sprung weight is the weight located above and supported by the pockets of compressed gas. The aircraft's unsprung weight (i.e. tires, wheels, brakes, bogie beams, lower strut components, etc. of which weight remains as a constant), is subsequently added to the sprung weight at each landing gear to determine the total weight supported at each strut. Summing all weight measurements determines the aircraft total gross weight. Comparing the weight supported by the combined main landing gear, as compared to the weight supported by the nose landing gear, identifies the aircraft CG (Center of Gravity).

Landing gear strut pressure changes are measured at a very high sample-rate. The rate of pressure increase within each strut is proportional to the rate of strut compression. The compression rate of the strut identifies the collapse rate of the landing gear strut. The collapse rate of the landing gear strut (corrected as to vertical by inclinometer) is the vertical sink-speed of the aircraft, as it makes initial contact with the ground.

Primary areas of concern and failures relate to hard landing events and maintaining the proper hydraulic fluid level within the shock strut. These two concerns have historically caused failures & aircraft mishaps, and have been highlighted with recent incidents. Aircraft have experienced mishaps caused by hard landings, and/or improper landing gear shock strut fluid level. Recent technical advances in programmable, digital, COTS data recorders (see Figure 1) make possible a single system that will measure aircraft weight and CG, detect hard landings and verify proper fluid level utilizing very simple, active, pressure measurements. The proposed system will alert maintainers/operators to a potentially dangerous aircraft condition that can be addressed before leading to component failure and aircraft mishap. Recent field-testing of operational aircraft landing gear struts has revealed that the pressure measurements are sufficiently accurate to determine when a landing gear shock strut is improperly serviced to the necessary fluid level.

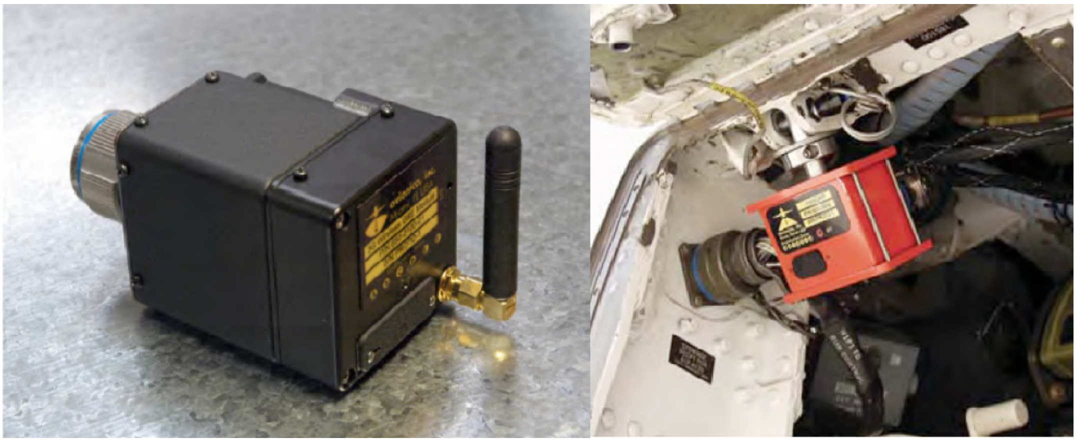

Figure 1. Wireless Flight Data Recorder (L) and Flight Data Recorder Installation on aircraft (R).

The data recorder can be programmed to process landing gear strut internal pressures for events before and after the WOW indication signal (see Figure 2). In-flight pressure data that varies from predetermined aircraft values will trigger a fault signal to a ruggedized Fault Display Unit (FDU) mounted in an easily visible location for a ground maintenance/pre-flight check (see Figure 3). Similarly, pressures that exceed a predetermined aircraft value shortly after WOW indication can be programmed as a "Hard Landing" event, and trigger the fault display flag.

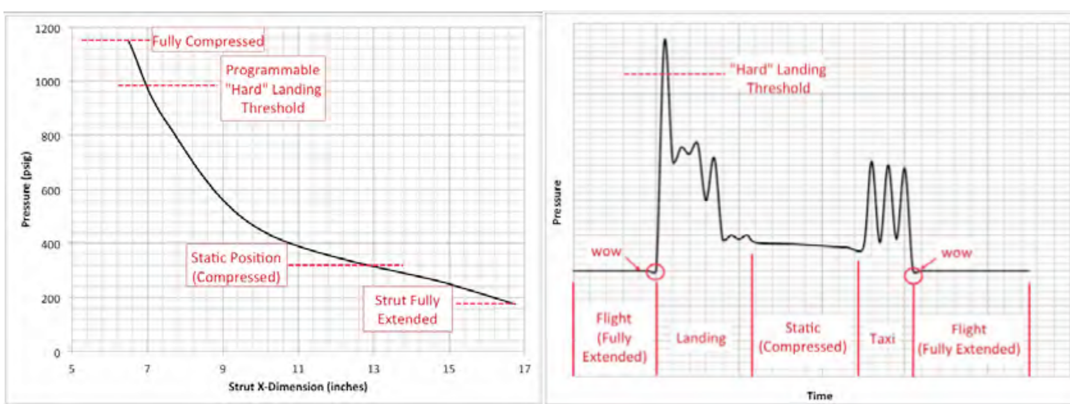

Figure 2. Representative Landing Gear Shock Strut Load-Stroke Curve (L), and Flight Event Pressure Values (R).

The strut seal friction (as related to temperature and adjusted for various pressure ranges) can be measured at the time of system installation onto the aircraft. Friction will distort strut pressure depending upon which direction the strut is currently moving. When the strut is compressing from weight being added, pressure will remain constant until enough weight has been added to overcome the seal friction. Strut seal friction will "partially support" the additional weight being applied; thus the strut pressure will be "artificially low" as the additional weight is applied.

When the strut is extending from the removal of weight, strut seal friction will "partially trap" the internal strut pressure, until enough weight has been removed to allow the strut to move. Thus the strut pressure will be "artificially high" as additional weight is removed. These strut seal friction distortions to internal pressure are symmetrical; to the positive and negative, and the strut seal friction distortions to internal pressure are proportional to increases in strut pressure (higher friction with a heavier aircraft and lower friction lighter aircraft).

These frictional distortions of pressure change in relation to changes in temperature. Also, as the aircraft taxi, prior to take-off, the struts are exercised with the bumping along the taxi-way. High and low strut pressure peaks can be measured, stored and averaged, to eliminate the pressure distortions caused by strut seal friction.

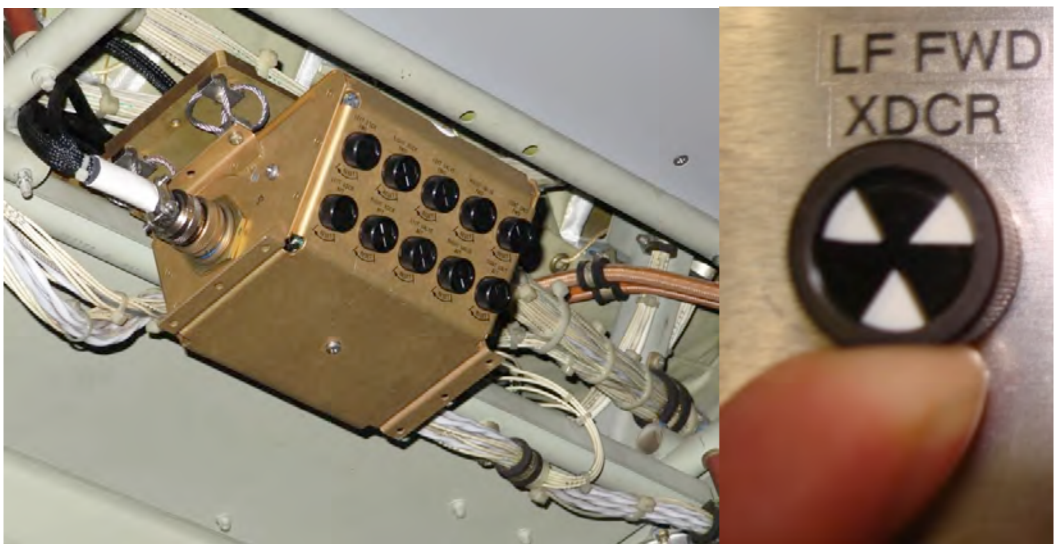

Figure 3. Aircraft Antiskid Fault Display Unit (FDU) (L) and Tripped Fault Flag Indicator (R).

ES3 has recently been working with NTT Aerospace to develop an automated Aircraft Landing Gear Fluid Level Monitoring and Hard Landing Indication System. The premise of the ES3 / NTT effort is to utilize pressure sensors to analytically determine both the landing gear shock strut fluid level and allow for a hard landing indication provision. At the heart of this system is a wireless miniature data acquisition system, shown in Figure 1, to capture and process the pressure data. A full function landing gear SHM system would utilize a similar or expanded version of the same miniature data acquisition system included in the Level / Hard Landing Indication System. Because the fluid level monitoring system can be utilized to determine aircraft weight and balance (CG), it is considered the first function of the SHM system.

Such additional capabilities may require greater memory resources and data channels than the simplistic fluid level monitoring; but in theory a data acquisition system could be specified that would have sufficient hardware capacity to incorporate all future SHM features.

STRUCTURAL HEALTH MONITORING SYSTEM FEATURES

There is a need to gather in-service fatigue loads data on landing gear components, with the ability to remain on aircraft for an indeterminate amount of time. These structures are typically designed from high strength aluminum and high strength steel materials, which exhibit relatively brittle nature.

The typical qualification approach is designed and tested to 4-lifetimes originally; but it is increasingly common for legacy aircraft systems to exceed the original design spectrum. Nonetheless, current design practice in the landing gear industry is leading more and more Original Equipment Manufacturers (OEMs) to conduct digital fatigue analysis on components during the design phase. Such an approach can be fairly accurate at computationally determining the safe-life of a particular design, if the material properties and actual service loads are known. SHM data quantifying the actual service loads, can be utilized to determine the actual fatigue structural health of any landing gear component.

Additionally, other operational parameters, shown below, can be determined with usage of multiple sensor types, coupled with appropriate analysis.

- Aircraft weight
- Aircraft CG
- Aircraft sink-speed at landing and throughout landing event
- Life-time landing load tracking
- Strut hydraulic fluid level monitoring
- Oxygen contamination monitoring (to catch internal corrosion earlier)
- Tire pressure monitoring
- Brake and anti-skid monitoring

CONCLUSION

The immediate benefit of the fluid level & landing energy monitory / SHM system will be the ability to warn operators of low hydraulic fluid level and hard landings. Automated determination of CG, weight and balance can follow this functionality. Measurement of landing gear strains/loads/accelerations and temperatures will lead to greater understanding of each aircraft's operating parameters. This, in turn, will allow for more intelligent maintenance requirements, or inspection and repair intervals. This will maximize the utilization of the landing gear components, without compromising their safe operation; which will ensure life cycle cost reductions.

Other benefits will include:

- Ability to increase aircraft structural capacity or operational limitation
- Ability to decrease aircraft brake cooling times
- Ability to determine high load events, and notify operators for special inspections or removal