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Landing Gear Structural Health Prognostic/Diagnostic System

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Abstract

This paper provides information on the development of a landing gear Structural Health Monitoring (SHM) system that provides prognostic/diagnostic HUMS capabilities through direct load measurement in addition to strut servicing detection algorithms. The direct load measurement approach is a paradigm shift from current methods of tracking fatigue damage of airframe landing gear systems and fuselage support structures, which depend on data collection of aircraft parameters recorded onboard at various sampling rates by SHM devices. The landing gear SHM provides direct loads measurement, weight/balance calculations, and the ability to perform Condition Based Maintenance (CBM) on the landing gear components. NAVAIR contracted with ES3 to support the development of the landing gear SHM via the Small Business Innovative Research program, via a Phase II award on the N121-043 topic. The proposed solution will be directly transferable to other Navy, military and commercial aircraft platforms. This paper will address the following topics in the area of HUMS and CBM: (1) advanced landing gear sensors for direct load measurement; (2) Data fusion of direct loads monitoring data into fatigue life assessments; (3) Paradigm shifts in aircraft maintenance utilizing strut servicing detection algorithms; (4) System verification and validation; and (5) Safety and maintenance benefits.

Keywords: landing gear, prognostic, diagnostic, monitoring, health, maintenance, fatigue, sensors

Introduction

NAVAIR contracted with ES3 to continue development of a landing gear Structural Health Monitoring SHM system through the Small Business Innovative Research (SBIR) program, via a Phase II award on the N121-043 topic. Although the primary focus of the development program is for fixed wing aircraft, the proposed solution is directly transferable to other Navy and commercial fixed wing and rotorcraft. The system presented address aircraft Health and Usage Monitoring System (HUMS) and Condition Based Maintenance (CBM) in the following topic areas: (1) advanced landing gear sensors for direct load measurement; (2) data fusion of direct loads monitoring data into fatigue life assessments; (3) paradigm shifts in

aircraft maintenance utilizing fluid-level detection algorithms; (4) system verification and validation; and (5) safety and maintenance benefits.
DOT/FAA/AR-04/6, Continued Evaluation of Spectrum Development of a Usage Monitoring Spectrum1 outlines several benefits of usage monitoring on airframes including extending retirement times and inspection intervals beyond initial certification. However, prior work in the field of spectrum development and usage monitoring has typically focused on the aircraft structure, with assumptions translated to the landing gear components without any direct measurement.

Landing gear is a unique, complex and critical system on aircraft that is a hybrid of structure and machine. Landing gear is second only to the propulsion system in regards to maintenance effort. They must carry high and varying loads but retain a lightweight, compact form. While most aircraft structures are made from ductile alloys that can endure crack growth over time; landing gear use very high strength, but brittle, alloys of steel, aluminum or titanium. These differences and other unique issues require distinct approaches with landing gear structural health monitoring methods2.

The same HUMS/CBM benefits applied to airframes can be realized for landing gear with specialized SHM systems. Through direct loads measurement, the ability to extend service life and remove components based on actual loading conditions can be achieved. The incorporation of CBM data into the maintenance practices can improve safety, increase aircraft availability, and save maintenance costs.

Early development of the subject landing gear SHM system was presented at the 6th European Workshop on Structural Health Monitoring, in a paper regarding Aircraft Landing Gear Fluid Level and Landing Energy Monitoring System3. The focus of that paper was the detection of improper fluid level and hard landings via the SHM system and sensors. The technological feasibility of the fluid level detection was accomplished in 2013 as part of the N121-043 SBIR effort. This paper advances the state-of-the-art via the miniaturization of sensors data collection systems rated for the severe landing gear environment at a high Technological Readiness Level (TRL). Figure 1 shows the sensor installation as flown on aircraft during a recent loads spectrum data collection effort.

LANDING GEAR SENSORS

The landing gear design and approval process significantly differs from the aircraft structures process. "Damage tolerant" methodologies are used in airframe design. This design process provides a safe period of operation for cracks to develop and grow in structural members before being detected and repaired. In contrast, landing gear utilizes a "safe life" design method. This approach is due to the materials used and constraints applied to landing gear. "Safe life" designs do not permit or consider cracks. As a result, implementing SHM

Figure 1: Sensor assembly installation on landing gear.

on landing gear requires a unique solution that is targeted specifically to landing gear[4]. Examples of advanced landing gear sensors are the pressure sensor in Figure 1 and the load pin in Figure 2. The pressure sensor was recently used to collect strut pressure data during a load survey flight test. The advanced landing gear load pin replaces the drag brace pin to directly measure drag loads. This instrumented load pin was utilized during high-fidelity laboratory testing on a full landing gear assembly.

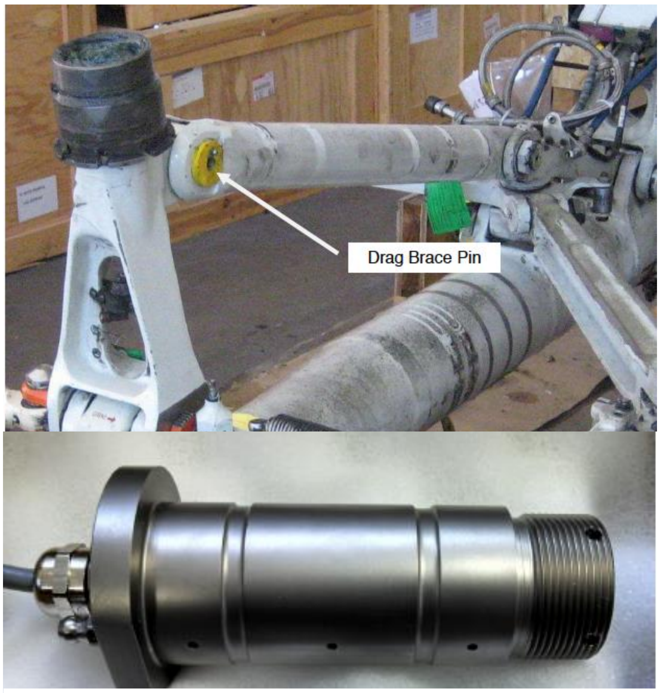

Figure 2: Landing gear load pin.

The landing gear SHM system under development includes sensors placed in direct load paths to measure loads in vertical, drag and side paths. In addition, the system sensors provide the capability to monitor brake torque and strut extension.

3. RUGGED DATA ACQUISITION SYSTEMS

ES3 has leveraged the specialized products and services from Flight Data Systems Pty. Ltd. (FDS) located in Melbourne, Australia, specializing in Flight Data Management. Since 1990, FDS has been supplying flight data acquisition units, Flight Data Monitoring (FDM) and readout services to commercial and military customers around the world. FDS also manages a complete logistics management service for the Australian Defence Force (ADF).

FDS has adapted the Remote Data Concentrator (RDC) hardware to fit the specific ES3 SHM system requirements. The RDC has been adapted to the harsh landing gear environment and serves as the primary data acquisition unit. Collected data is transferred to a Central Control Unit (CCU), derived from the FDS Modular Acquisition Unit (MAU). The CCU aggregates and process sensor data from all connected RDCs. Examples of the derived products are shown in Figure 3.

Figure 3: CCU (left) and RDC (right) from FDS.

The ruggedness and size of the RDC allow it to be installed directly on the landing gear assembly. The CCU can be installed in the landing gear bay area or in another location inside the aircraft. The CCU transmits landing gear sensor data to control/recording devices located elsewhere inside the aircraft.

4. DATA FUSION AND HUMS INTEGRATION

This landing gear SHM system also allows data fusion of direct loads monitoring data into fatigue life assessments. This feature is provided via utilization of communication to platform HUMS and associated flight records for data assurance purposes. The interface and communication of the SHM control units to the aircraft HUMS equipment provides the ability to synchronize loads data, allowing for elimination/reduction of estimates on landing gear loads usage and service life. An example of the benefits of direct loads monitoring is shown in Figure 4. In this example, the aircraft systems or aircrew did not detect a hard landing. However, the nose landing gear (NLG) became fully compressed for several cycles during the landing. An integrated SHM system could have alerted the aircrew and/or ground crew that the NLG should be inspected, thereby enhancing operational safety. The other scenario is similar. The aircrew could experience what they believe was a hard landing. With an integrated SHM system directly measuring landing gear loads, the system could confirm the hard landing or indicate the measured loads were within safe operating parameters. Thus, the SHM system can reduce maintenance costs and increase aircraft availability by reducing unnecessary maintenance.

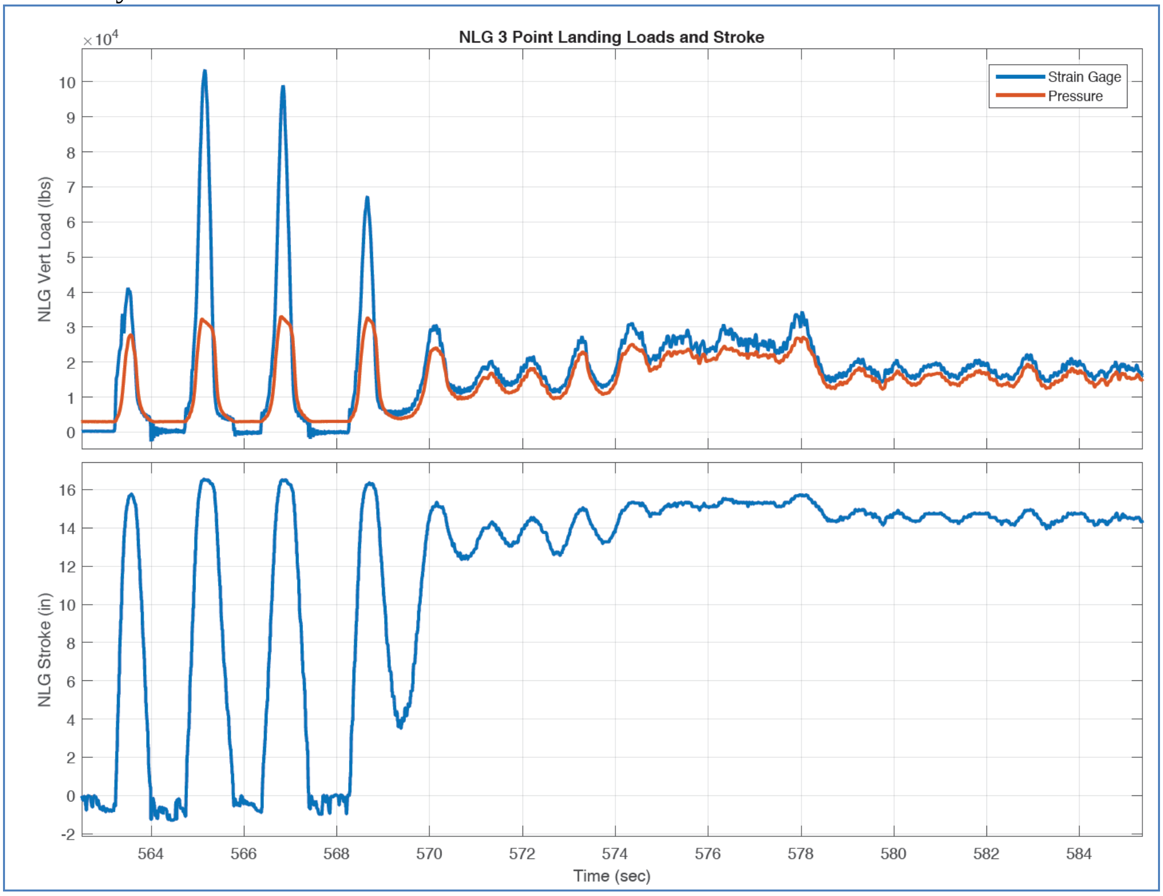

Figure 4: NLG strut bottom out during landing.

The SHM technology and algorithms also provide the ability for a paradigm shift in aircraft maintenance, utilizing fluid-level detection algorithms. Previously, detection of an improperly serviced strut with weight on aircraft wheels was not possible. The incorporation of the SHM sensors and unique aircraft algorithms changes the maintenance approach, allowing for appropriate CBM based on the actual condition of the landing gear component service condition.

Laboratory testing of the SHM components using early TRL technology has also been completed. The system development has transformed into form, fit and function hardware in a high-fidelity laboratory environment. Future testing will include installation and flight testing on an operational aircraft. A sample of data collected from the loads survey flight testing is shown in Figure 5.

The SHM technology also provides a safety benefit with the improvement of weight and balance calculations. The landing gear sensors and associated control/interface units provide the ability to calculate actual weight and balance information. This information can then interface with other platform HUMS systems for use in improving maintenance practices, or enhancing crew safety during operations.

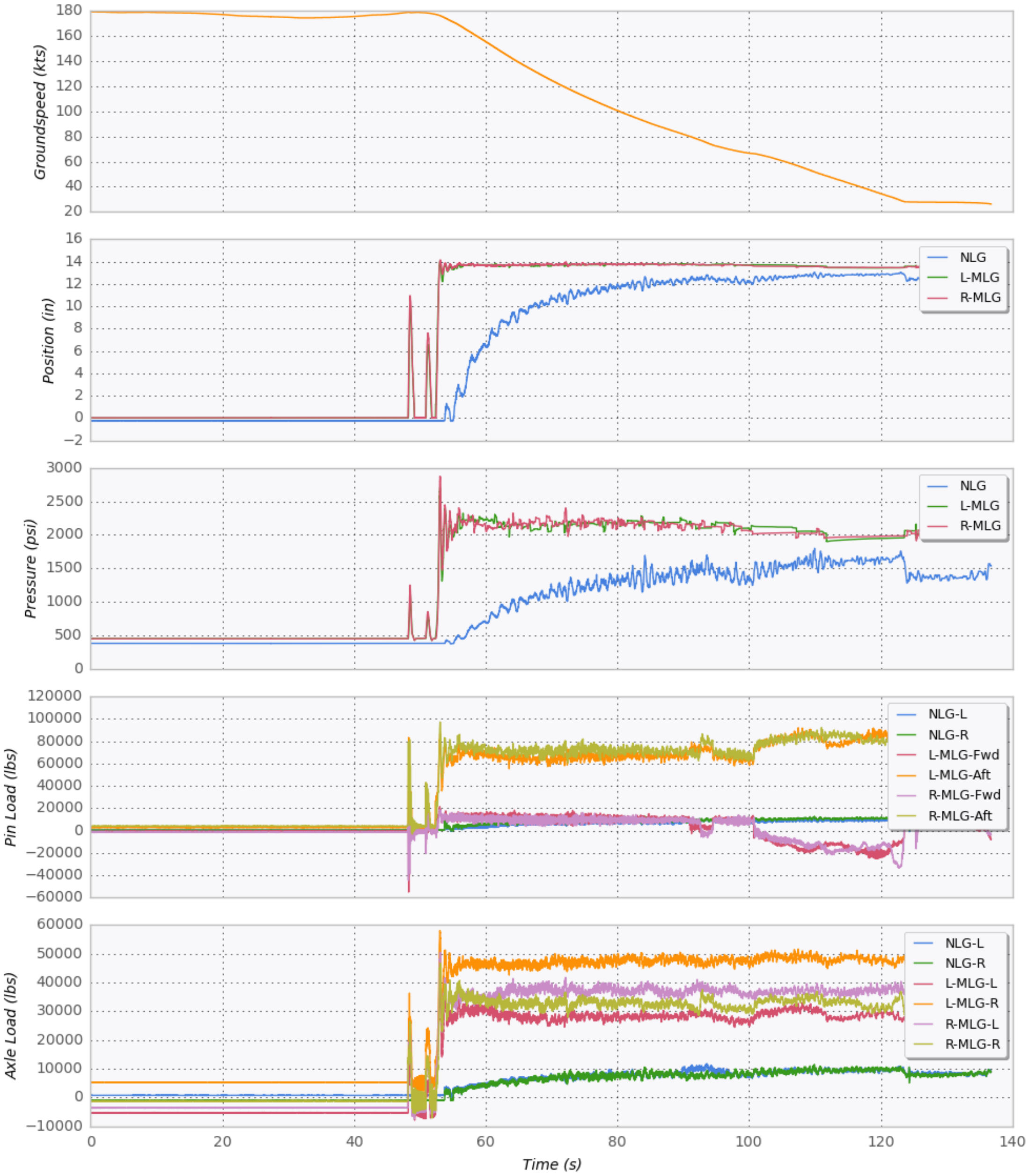

Figure 5: Example landing data from aircraft loads survey.

5. CONCLUSION

The SHM system discussed in this paper has demonstrated the viability of a landing gear structural health monitoring system. The advances in the technology readiness levels of the sensors and data acquisition system coupled with the analysis algorithms have readied the system for on aircraft testing. This system can benefit aircraft operators by increasing the operational safety and reducing the maintenance requirements while increasing the awareness of the landing gear condition.

There are still challenges with infrastructure that may limit the effectiveness that landing gear SHM systems can offer. Namely, the data transfer methods from the aircraft and long term retention of that data. Tracking of each landing component is also necessary to develop the fatigue spectrum unique to each component. This can be a complicated task due landing gear overhaul methods that may pass components from one aircraft to another.

Although obstacles currently prevent the realization of the full potential of landing gear health monitoring, the implementation of systems on individual aircraft can provide immediate benefits. This benefits include hard landing detection, strut operational readiness monitoring and improved weight and balance systems.

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