Advanced Fatigue Measurement and Prediction System Suitable for Critical Defence and Aerospace Structures

Final Report

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Abstract

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This document reports on the development and demonstration of a new generation of life cycle fatigue sensor technology, known as chameleon Strain Gauge (CSG®) or fatigue accumulation sensor. The developed sensor demonstrated the ability to accurately and consistently measure structural fatigue, together with reliable prediction of remaining fatigue life using AL 6061-T6 and CS 4340 sample coupons. Such sensor capability not only met but surpassed set specifications and expectations.

The physical nature, low profile (e.g. stamp size), of the sensor makes it suitable for applications where information on the structural integrity is critical to airworthiness assurance of aircraft components (e.g. landing gears, wing spars, fuselage bulk head.) Improved data acquisition protocols and procedures are required to ensure technology exploitation effectiveness, particularly for critical hard and less accessible components.

Résumé

Les aéronefs sont en constante évolution et leur efficacité ne cesse de s'accroître. De nouvelles technologies qui contribuent de manière appréciable à l'évolution de la nouvelle génération de systèmes aériens et spatiaux sont donc développées. Des capteurs sont mis au point pour modifier les systèmes de commandement et de contrôle, les commandes de vol, ainsi que les tâches et les programmes de maintenance. De plus, en raison de sa stratégie de défense et de sa directive sur la mise en œuvre des mesures de réduction des coûts, l'Aviation royale canadienne explore différentes options en vue d'améliorer l'efficacité de ses méthodes de gestion du cycle de vie et de maintenance des aéronefs.

Le présent document traite de la mise au point et de la mise à l'essai d'une nouvelle génération de capteurs de fatigue pour l'analyse du cycle de vie connus sous le nom de Chameleon Strain Gauge (CSGMD) (extensomètre caméléon) ou capteurs d'accumulation de la fatigue. Le capteur mis au point a démontré sa capacité à mesurer avec précision et de façon uniforme la fatigue structurale et à prédire de manière fiable la durée de vie en fatigue restante à partir d'échantillons

d’essai de AL 6061 T6 et CS 4340. Les capacités du capteur ont permis non seulement de respecter les spécifications et les attentes établies, elles les ont dépassées.

La composition physique du capteur et sa petite taille (de la grosseur d’un timbre) font en sorte qu’il convient à des applications pour lesquelles l’obtention de renseignements sur l’intégrité structurale est essentielle afin d’assurer la navigabilité des composants d’aéronef (p. ex. train d’atterrissage, longerons d’aile, cloisons de fuselage). Des procédures et des protocoles d’acquisition de données perfectionnés sont nécessaires afin d’exploiter avec efficacité la technologie, plus particulièrement en ce qui a trait aux composants essentiels qui sont difficiles d’accès.

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Final Report

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Executive Summary

A direct sensing of stress and fatigue and their visualization is very attractive and has been pursued for decades. Prognostica® is a new and unique tracking, sensing, and prognosticating technology that allows for exactly that. It is a revolutionary wireless fatigue analysis system designed to forecast the lifetime of parts and/or objects, composed of multi-natured materials, including but not limited to metals, resins, plastics, and composites.

Prognostica® has perfected the method of direct sensing of stress and fatigue, reduced it to practice, and demonstrated that excellent correlation with established science can be obtained. The technology is addressing the very state of element's fatigue, while providing direct information of cumulative effect of host structure exposure to loads and cycles. More than that, this type of prognostication methodology allows visualizing the sites of particular stress/strain concentration and crack initiation as complementary to modeling through a design cycle, such as utilization of FEA.

The main element of the technology is a CSG® sensor. In simple description the CSG® sensor is a custom-engineered thin metal strip of suitable alloy, which is applied by appropriate adhesive to the host structure under investigation. When attached to a host structure the CSG® sensor undergoes changes in its molecular domain and photonic properties corresponding to the structural changes due to stress and fatigue of the host element. By processing the optical data, the extent of cumulative change in stress and fatigue state of the host element, as well as prediction of the expected life to critical fatigue levels is assessed. That is, in a nutshell the methodology of the Prognostica® technology. The significant merits of this form of sensor technology comprise:

- No power or external, wired connections are required;
- Flexible sensors easily conform to complex surfaces, such as holes and corners, and withstand a broad range of operating environments;
- Sensor is environmentally robust, can be installed permanently;
- Fatigue information may be extracted from the sensor using optical technology means, while indicating surface changes still invisible in the actual host structure;
- Suitable for archiving and investigative purposes.

Prognostica® is distinctive in its potential for applications of fatigue measurements in locations non- accessible by all other methods. Prognostica® also provides the capability to uniquely evaluate load amount in case of random loading conditions (very common for aircraft components), which can be used as input data for FEA to more accurately model component fatigue damage and remaining life. The use of CSG® sensors does not interfere or obstruct any existing test procedures and can reduce testing and re-engineering periods for all components, thus providing the opportunity of significantly reducing production costs.

Abstract

The DIR project studied and demonstrated the ability of the Prognostica® technology to accurately and consistently measure structural fatigue, together with reliable prediction of remaining fatigue life. Working with AL 6061-T6 and CS 4340 coupons, the performed activities verified the evident ability of the CSG® to not only reach, but surpass the set milestones. The produced coupons were outfitted with the CSG® and cyclically loaded under varying deflection parameters with a constant R= -1 symmetry value until failure. All results data for calibration and forecasting was gathered and recorded. Based on the results achieved in this effort, it is evident that the technology has excellent reliability, repeatability, accuracy, and reflects the real-time fatigue conditions of the base structure in its entirety, not calculated values or strain readings from only one small area. The principal investigator is confident that the Prognostica® system and methodology, based on the proposed concepts, has a strong potential of becoming an essential part of the fatigue measurement and prediction system for critical defence and aerospace structures.

Systems Engineering & Application Methodology

Initial application methodology development began with the selection of the appropriate adhesive for our specific application. Many adhesives ranging from cyanoacrylates to epoxies to methacrylates went through vigorous testing and a summary of the results is shown in Table 1.

- Ease of use was based on the ease of applying the adhesive, working tack time, curing time, and the associated handling protocol for the specific adhesive in question.
- Bonding strength was determined by applying the peel test both by hand and with a tensile apparatus.
- Load reflectivity is based on the ability of the CSG® gage to reflect the appropriate data without the underlying adhesive layer buffering the results and thus creating error in load reaction values.
- Cost analysis is based upon the cost per application including all necessary application tools for the specific adhesive in question.

Each adhesive was judged on a scale from 1 to 5 in the above mentioned categories; poor to excellent (high cost to low cost) respectively.

Adhesive	Ease of Use	Bonding Strength	Load Reflectivity	Cost	Notes
Cyanoacrylate 101	2	5	4	3	Great Bonding strength but extremely difficult to apply because of short curing time
Cyanoacrylate 103	1	5	4	3	Great Bonding strength but extremely difficult to apply because of short curing time
Epo-tek Epoxy 1	3	3	4	2	Average result, Bond is not always strong, Poor repeatability
Epo-tek Epoxy 2	4	3	4	2	Average result, Better than Epo-tek 1 because of higher viscosity
Epo-tek Epoxy 3	4	3	4	2	Average result, Better than Epo-tek 1 & 2 because of higher viscosity
RTC Epoxy	3	4	3	3	Difficult to have repeatable consistency, poor load reflection
Generic Epoxy	4	4	3	5	Good for its cost, better results than high end epoxies, inconsistency between batches
TDS 5012	4	3	2	5	Very easy to use, poor bonding strength, rubber composition = very poor load reflection

Table 1 – Summarized adhesive selection chart

Experiments were initially performed using 2 application techniques and a constant press method (pressure clamps, Figure 1). Gage application with transfer tape, and without (Figure 2). The transfer tape method replicates the methodology used for strain gage application and thus will not be discussed here. Both have shown promising results but the technique using the transfer tape provides a better result as the adhesive does not come in contact with the top of the gage during mounting. When this happens, the gage surface needs to be cleaned and the cleaning procedure does not always remove all adhesive residues and additionally, has the ability to leave residual stresses behind. Thus, application with the transfer tape was used for preliminary application methodology development.

Figure 1 – Pressure clamp

Figure 2 – CSG® application with/without transfer tape

After continued CSG® application the results showed that the pressure clamp method was causing an uneven adhesive layer between the CSG® and the host element. This causes a problem due to uneven buffering of the fatigue data transmission from the host element to the CSG® surface. In order to resolve this issue, a device called the gage attachment fixture (GAF) was designed and fabricated (Figure 3). Comparison testing was done using clamps, hand presses, and parallel block presses to determine what fixture or lack thereof, was the best solution for gage mounting. The reason the GAF was selected was its ability to distribute pressure evenly on the CSG® during mounting by employment of compressed air "balloon"; this allows for a controlled and consistent adhesive layer to be formed. The other mounting methods are limited as the adhesive thickness is not controlled, high residual stresses are built up in the gage, and mounting to components with various shapes, configurations, materials, and textures is next to impossible.

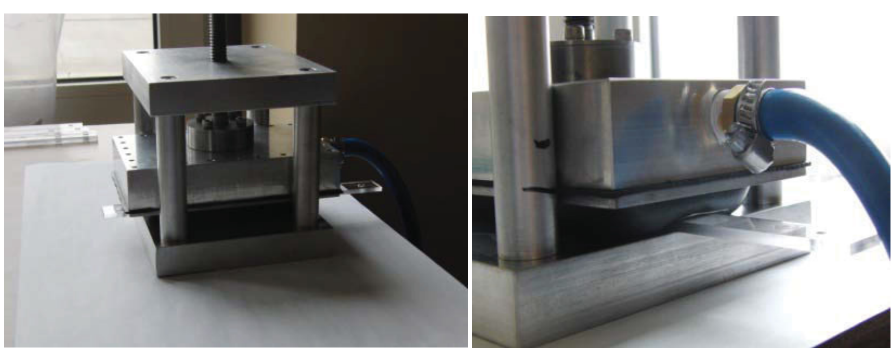

Figure 3 – GAF (Gage attachment fixture)

The GAF is a device that uses air pressure to expand a rubber sheet almost like a balloon. The "balloon" concept is what provides for even distribution of pressure on the gage surface and allows for controlled adhesive thickness while generating no residual stresses on the gage. The balloon concept also allows for gage application to complex geometries including non-flat and cornered areas. The GAF is attached to a small air compressor that provides constant pressure to the "balloon." The GAF is extremely easy to use based on its simple design concept. There is no special training needed and the cost of this application method is very low in comparison to other gage mounting tools/equipment used in other areas of NDT (non destructive testing). An in-field version of this mounting tool is currently under development. It is also important to note, that gage application time is approximately 2 min (CSG® to component with press) and approximately 1 hour for curing.

Very vigorous and detailed adhesion and loading testing was performed to select the appropriate gage material. The material and characteristics of the sensor are extremely important. The sensor must be made of an isotropic material as to detect stress/strain in any direction. Additionally, the sensor must be relatively thin (~15 microns) to be sensitive enough to register all fatigue loading information from the host structure. The sensor material that has been selected is based on a proprietary alloy and thus will not be discussed here. This proprietary alloy allows for the use of the CSG® for all loading spectrums, components, and environments. It can be referred to as a "one size fits all" fatigue sensor.

Optical Reader Equipment & Tooling Selection Evaluation

The evaluation of different optical reading methods and the associated tooling and equipment was carried out throughout the project term. The evaluation began with three main optical reading devices; A Canon Canoscan LiDE-700F flat bed scanner (Figure 4), Dalsa BOA-640 vision system; industrial camera for machine vision (Figure 5), and a metallurgical microscope (Figure 6).

Figure 4 – Canoscan LiDE 700F, 9600dpi

Figure 5 – Dalsa BOA-640 vision system

Figure 6 – Metallurgical microscope

The Canon scanner was the clear choice from the initial 3 devices tested. It provides a perfectly flat surface and a consistent lighting environment. This is ideal for laboratory use where flat coupons are tested. The metallurgical microscope is very promising in theory but is too bulky and light sensitive to prove useful in practical analysis. The Dalsa camera also proved to be light sensitive and ideal lighting conditions need to be created in order to gather the appropriate readings from the CSG® (this idea will be pursued further in future development).

After gathering and analyzing the positive results from the flat bed scanner, several portable scanning devices were evaluated in order to determine their applicability in both laboratory and in field operation. The PlanOn pen scanner (Figure 7) and PlanOn SlimScan (Figure 8) were both tested and evaluated. The PlanOn pen scanner initially showed favorable results. The main issue we have found with this tool deals with the coupon alignment and the proceeding lighting changes. Since the tool is hand held, there is a greater chance for error when scanning due to the angle and/or position at which the pen scanner is held. A simple guide-rail system scanning jig (Figures 9 & 10) was designed and built to allow for accurate coupon alignment and scanning in order for repeatability and accuracy to not be a concern.

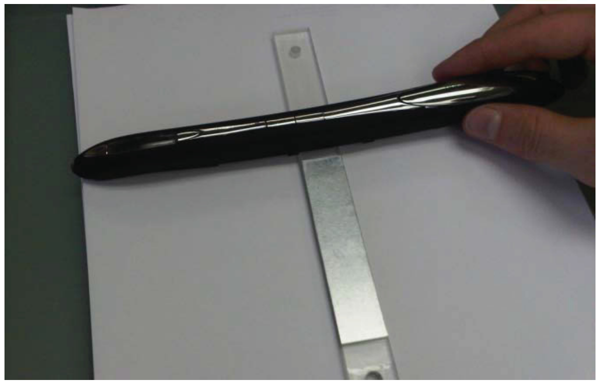

Figure 7 – PlanOn pen scanner

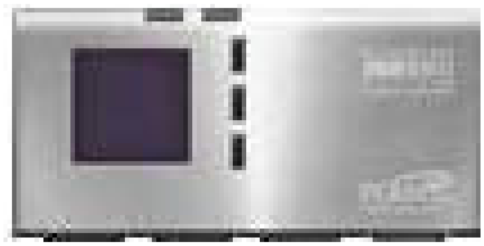

Figure 8 – PlanOn SlimScan

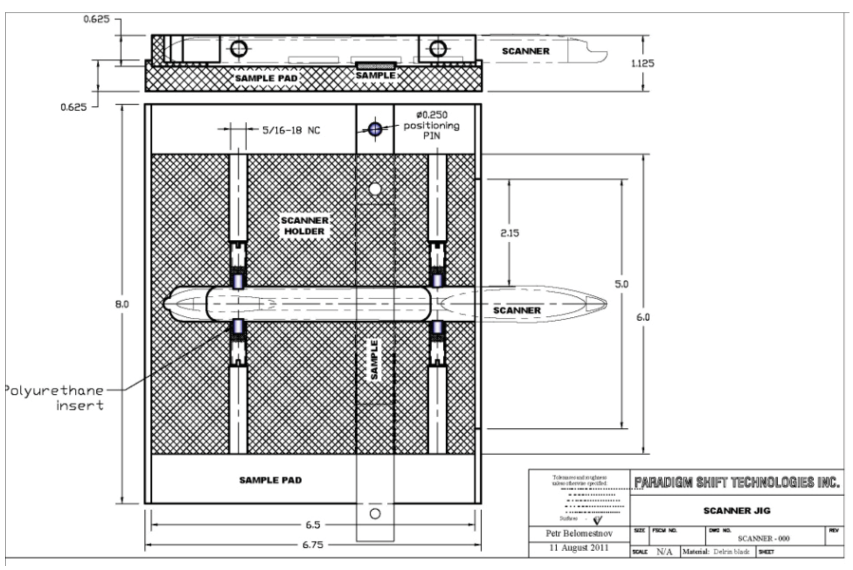

Figure 9 – Engineering design of scanning jig

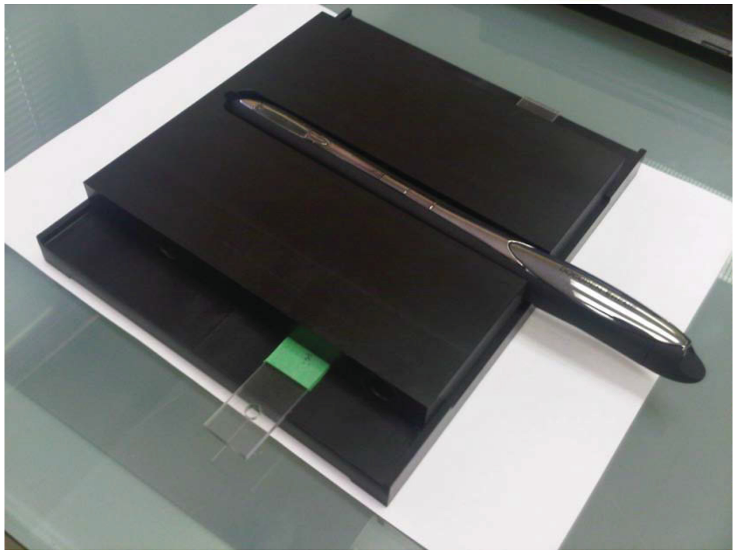

Figure 10 – Scanning jig in use with PlanOn pen scanner

The use of the scanning jig helped tremendously with CSG® alignment but light sensitivity remained a concern. The same coupon under different lighting conditions would present different CSG® readings. This confirms poor repeatability and consistency and therefore the PlanOn pen scanner option is not advanced enough yet as a technology and tool to fulfill the needs of this project.

The same issues were encountered with the PlanOn SlimScan. Both the scanning angle and lighting conditions play an enormous role in the quality of the readings gathered. In our opinion, neither of these scanning tools is technologically advanced enough to provide the appropriate solutions for our application.

Due to its simple operation and clear optical image results after the scan is complete, the Canon flat bed scanner continues to be the data acquisition tool of choice for laboratory use. This is mainly due to the controlled lighting by the top lid and layout of the coupon on the scan bed. The rigid internal frame on the scanning bed allows for the alignment of the coupon to be the exact same every time; thus, achieving high repeatability and consistency with every reading.

Optical Data Analysis Methodology Evaluation

Custom analytical software (Figure 11) has been developed to accurately analyze the CSG® and output the appropriate parameters. The software automatically subtracts the initial CSG® image (zero image) from the proceeding readings allowing for initial defects such as dust/dirt particles, areas of improper adhesion, residual stresses, etc. to be removed from final output reading.

The software analyzes the granularity of the desired CSG® sensor portion on a 256k color scale from white to black per pixel. This allows for an extremely precise analysis of the CSG® surface and therefore of the base component in question. The software also has the ability to present the accumulated fatigue value for the base component. The accumulated fatigue value is a measure of component life expended to the specific point in time at which the reading is being taken. This value is dependent on the loading and cycle parameters. The closer the value gets to 1 the higher the probability of component failure. This value can be presented for the entire CSG® surface or the image can be split into smaller sections (1 - 10^6) and a value can be presented for each of the sections. This becomes extremely useful for identifying critical areas where accumulated fatigue damage may be higher than other areas of the component. It is also extremely useful for analyzing damage precursors such as cracks and delaminations in the base component.

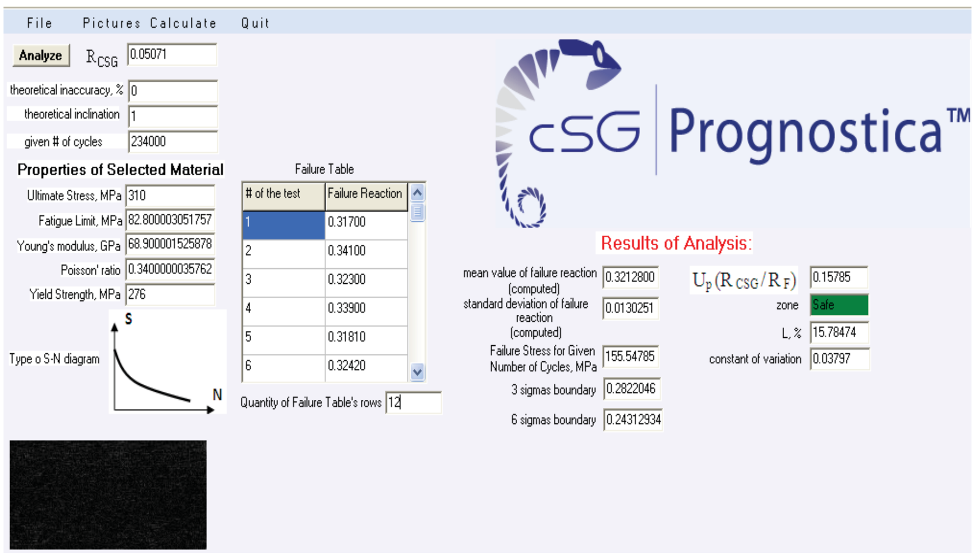

Figure 11 – Custom CSG® analysis software

The software outputs a lot of information that will be useful to the operator. The most important of which are the values listed in the far right column; fatigue accumulation value (0-1), zone (green – safe, yellow – caution, red – failure imminent), and expended life percentage (0-100). Based on these 3 values, the operator can determine if the component passes inspection or is condemned and must be either repaired or replaced.

The example below, Table 2, shows data collected during an experiment where a flat coupon having 3 non-thru holes was cyclically loaded on the Instron fatigue frame. The purpose of the experiment was to develop methodology in regards to complex loading scenarios so that a correlation formula can be derived in order to not have to destroy any live components for calibration. The results from this experiment will not be presented here.

# of cycles	R at Zone I	U_p at Zone I	R at Zone II	U_p at Zone II	R at Z one III	U_p at Zone III
50000	0.1050	0.3137	0.1247	0.3726	0.1237	0.3696
100000	0.1571	0.4694	0.1875	0.5602	0.1875	0.5602
150000	0.1901	0.5680	0.2082	0.6221	0.2226	0.6651
200000	0.2143	0.6403	0.2288	0.6836	0.2481	0.7413
250000	0.2299	0.6869	0.2401	0.7174	0.2609	0.7795
300000	0.2299	0.6869	0.2447	0.7311	0.2674	0.7989
350000	0.2442	0.7296	0.2612	0.7804	0.2752	0.8222
400000	0.2517	0.7520	0.2647	0.7909	0.2830	0.8455
499018	Failure in Zone III					

Table 2 – Example showing use of color coding

CSG® Application & Measuring Methodology Development

Calibration dependency graphs needed to be created for both the CS 4340 and AL 6061-T6 coupons (Figure 12). The calibration graphs are created by loading the laboratory coupon specimens on the fabricated bend-loading apparatus (Figure 13) until failure (coupon breakage) and recording the CSG® values at set intervals, as determined by the experimental plan. Having these calibration curves allows for a more precise reading of fatigue accumulation and provides the needed basis for accurate prognostication of remaining life and failure for the host material.

Figure 12 – CS 4340 & AL 6061-T6 Coupons

Figure 13: Laboratory bend-loading apparatus

The calibration graph below (Figure 14) shows the results from loading 6 - AL 6061 T6 coupons of identical geometry on the bend-loading machine (R= -1) with a deflection of 12mm (P= 8.78 kN) at a frequency of 5Hz. The results show that the CSG® reaction value (computed value of reading taken from CSG®) follows the same trend for every coupon. These results are clear evidence that there is excellent repeatability of the CSG® response (± 6%) under the same defined loading parameters. Excellent reliability is also exhibited since $CSG^{®}_{1}$ can be used as the reference sensor with the proceeding 5 CSG® sensors as correlating sensors.

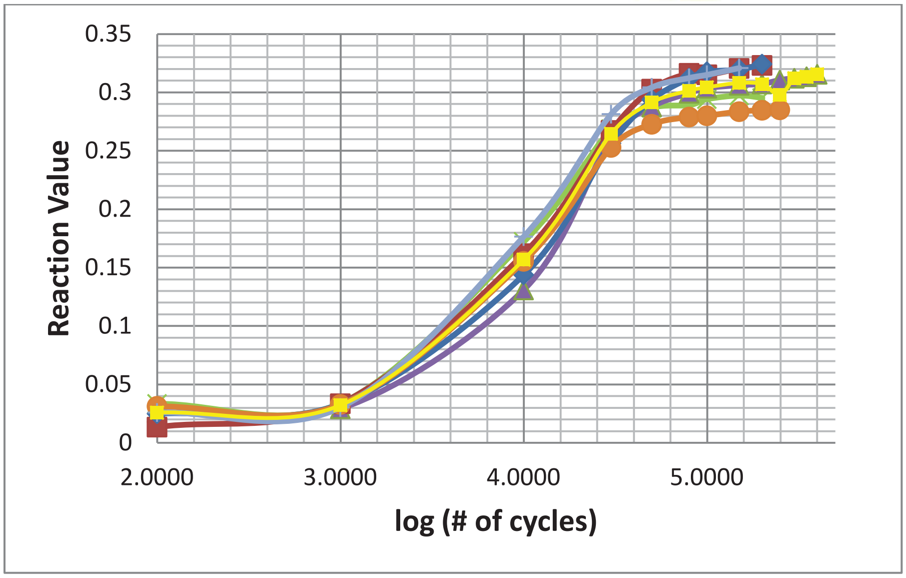

Figure 14: CSG® reaction value vs. # of cycles (logarithm) for AL 6061-T6 @ 12mm

The calibration graphs below (Figures 15 & 16) are the fatigue damage accumulation (fatigue growth) results for the above experiment (12mm deflection) and results for the same coupon grouping (same material and geometry) loaded on the bend-loading machine (R=-1) with a deflection of 15mm (P=10.94kN) at a frequency of 5Hz. The results once again clearly show that in both experiments (12mm & 15mm) the fatigue accumulation values follow the same trend line and therefore the information gathered from only one set of calibration experiments (i.e. 12mm) can be used to prognosticate failure not only under the same loading parameters but for different parameters as well (within practical reason, approx. ±15%). Particular consideration should be given to the U_p value (fatigue accumulation) at failure and its consistency in prognosticating failure; not the number of cycles at which failure occurs as that value is known to have a great deal of scatter (error). The U_p at failure for the same grouping of coupons under identical conditions will be different. This is due to the scatter effect of the material itself and cannot be avoided. This is the main reason as to why safety factors are put in place for component and structure design.

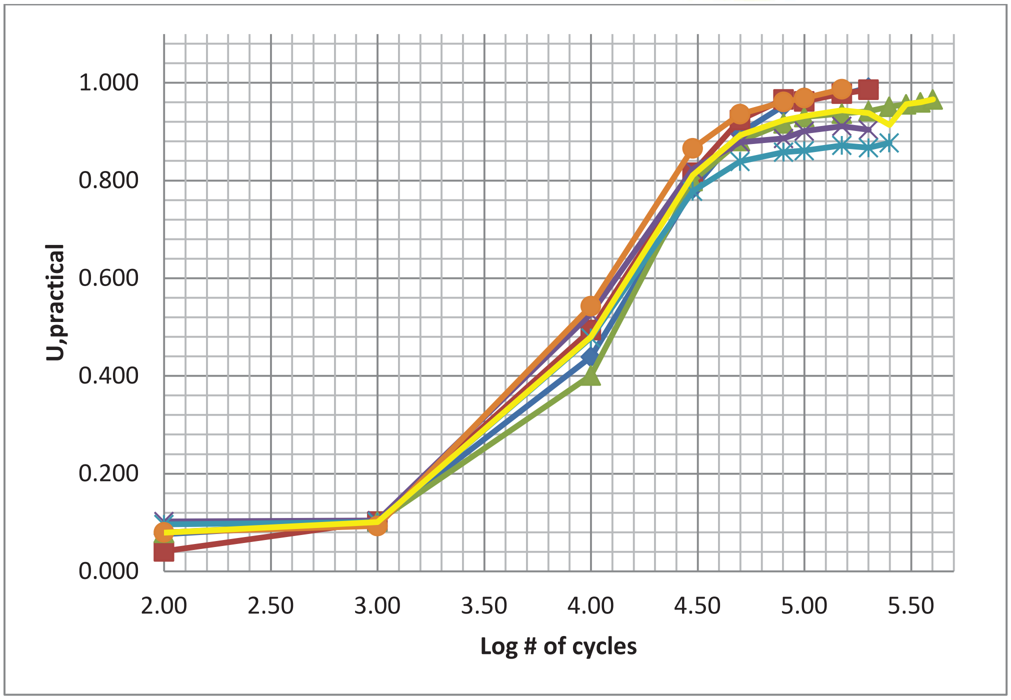

Figure 15: CSG® fatigue accumulation vs. # of cycles (log) for AL 6061-T6 @ 12mm

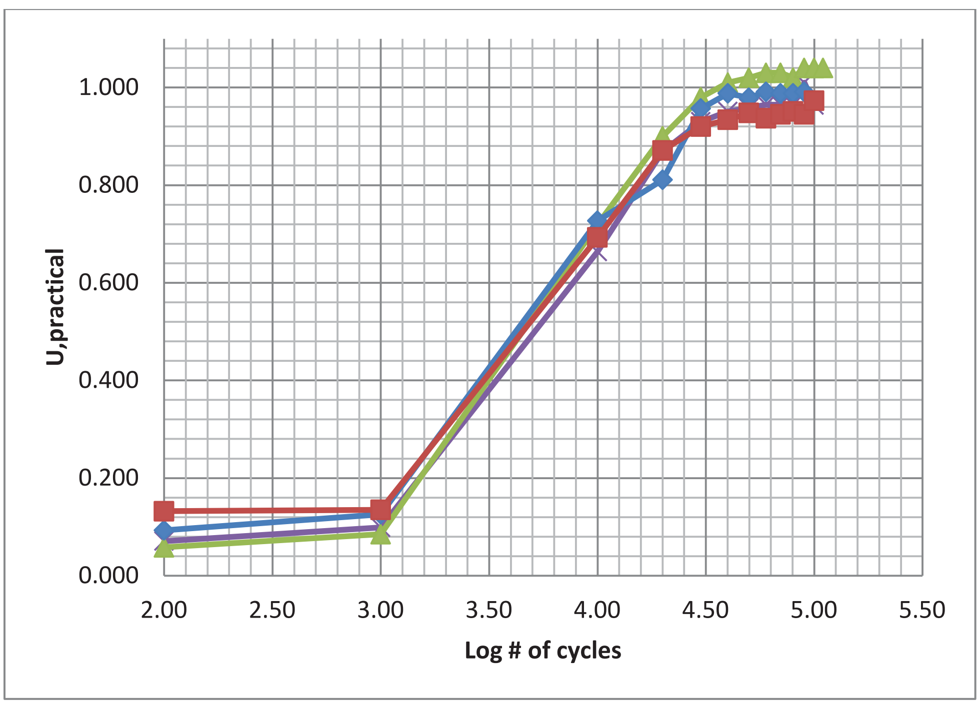

Figure 16: CSG® fatigue accumulation vs. # of cycles (log) for AL 6061-T6 @ 15mm

Prototyping & Integration of CSG® Test Kit

An evaluation kit has been prototyped but not all components of the kit are at full maturation. The kit will include but may not be limited to; CSG® sensors pre-cut to appropriate sizes, isopropyl alcohol and pads for cleaning host structure prior to sensor application, mounting adhesive including static mixing nozzles and application gun, portable GAF for affixing the CSG® to the host structure, optical reader device for taking images of the CSG® for analysis.

The optical reader device is the main element that has not reached maturation to be used in an in-field environment. We are currently working closely with Lumenera (Canadian leader in machine vision) and Metaphase Technologies Inc. (machine lighting specialists) to develop a custom proprietary camera assembly that will be able to actively and accurately gather all the needed data from the CSG® independent of the lighting and environmental conditions. This will provide the ability to analyze the CSG® sensors anytime and anywhere without having to sacrifice image quality that leads to inaccurate results.

Confirmation Test & Report for CSG® Methodology

Blind testing was completed in order to confirm the reliability and accuracy of the CSG® to actively measure fatigue and more importantly, prognosticate failure based on the accumulated fatigue. The blind testing was carried out by loading the coupons with an unknown (to the test administrator) load and removal of the coupons at an unknown (to the test administrator) number of cycles. The CSG® is then analyzed and a reaction value is computed using the custom proprietary Prognostica® software.

The table below (Table 2) displays the blind test results from a random amplitude (load) blind test performed with AL 6061-T6 coupons, all of identical geometry, on the bend-loading machine under controlled parameters (R= -1).

Total N	N	Δ (mm)	R-csg	Up-csg	Max. Stress (MPa)	Up-mill	% error
27982	27982	12	0.2495	0.821	163	0.811	1%
60438	32456	6	0.2492	0.821	81.8	0.812	1%
65561	5123	15	0.2760	0.909	209	0.912	0%
92218	26657	7	0.2818	0.928	97.5	0.913	2%

Table 3: Random loading blind test results; Al 6061-T6; 5 Hz

The results show a comparison between the CSG® accumulated fatigue reading ($U_{p\text{-}CSG}$) and the fatigue reading calculated with FEA software (ANSYS) combined with Mill-Spec S-N curve data ($U_{p\text{-}mill}$) (Mill-Spec Edition 5J) . Based on the obtained results it is clear that the CSG ® has excellent reliability (± 2%) when compared with theoretical data. It is also important to note that the CSG ® reaction reflects the real-time fatigue conditions of the base structure, not calculated values.

Direct comparison testing with strain gages (CSG® on one side, strain gage on the other) (Figure 17) was also carried out to further confirm the previous findings. It was also important to identify the ability of the 2 devices to work in unisons and to more actively determine the accuracy and reliability of the CSG® in comparison with already known and in use state of the art.

Figure 17: Comparison test setup. CSG® on side, strain gage on other.

The results below (Table 3) show a comparison between the CSG® accumulated fatigue reading ($U_{p\text{-}csg}$), the fatigue reading computed with theoretical strain combined with Mill-Spec S-N curve data ($U_{p\text{-}t}$) (Mill Spec Edition 5J) and the fatigue reading computed with the actual strain reading (experimental) combined with the Mill-Spec S-N curve data ($U_{p\text{-}g}$). Based on the obtained results from these experiments it is clear that the CSG® has excellent reliability (% error average of ± 4.5%). Error is measured between the $U_{p\text{-}csg}$ and $U_{p\text{-}g}$ as these are measured values and not strictly theoretical. It is also important to note that the CSG® reaction reflects the real-time fatigue conditions of the base structure in its entirety, not calculated values or strain readings from only one small area (surface area underlying the strain gage) of the host structure.

N	R-csg	U-p-csg	F-limit	Strain-t	U-pt	Strain-A	U-pg	% error
10000	0.1764	0.5967	857	0.00296	0.7246	0.00342	0.7981	25.2%
20000	0.2473	0.8364	723	0.00296	0.8589	0.00346	0.9571	12.6%
30000	0.2821	0.9542	697	0.00296	0.8996	0.00342	0.9813	2.8%
40000	0.3014	1.0193	689	0.00296	0.901	0.00346	1.0044	-1.5%
50000	0.3027	1.0239	673	0.00296	0.9227	0.00342	1.0163	-0.7%
60000	0.2985	1.0096	665	0.00296	0.9338	0.00343	1.0316	2.1%
70000	0.3025	1.0230	654	0.00296	0.9495	0.00344	1.052	2.8%
80000	0.2994	1.0126	650	0.00296	0.9554	0.00344	1.0585	4.3%
90000	0.3114	1.0533	649	0.00296	0.9568	0.00345	1.0631	0.9%
100000	0.3062	1.0355	648	0.00296	0.9583	0.00343	1.0603	2.3%
110000	0.3091	1.0429	647	0.00296	0.9598	0.00343	1.0603	1.6%
120000	0.3035	1.0238	646	0.00296	0.9613	0.00342	1.0588	3.3%
130000	0.3075	1.0373	646	0.00296	0.9613	0.00341	1.0557	1.7%
140000	0.2977	1.0043	646	0.00296	0.9613	0.00341	1.0557	4.9%
150000	0.2992	1.0094	645	0.00296	0.9628	0.0034	1.0543	4.3%
160000	0.3095	1.0442	643	0.00296	0.9658	0.0034	1.0554	1.1%
170000	0.3081	1.0395	640	0.00296	0.9703	0.0034	1.0625	2.2%
180000	0.3039	1.0252	637	0.00296	0.9749	0.00341	1.0706	4.2%
190000	0.3142	1.0599	635	0.00296	0.978	0.00342	1.0772	1.6%
200000	0.2990	1.0087	632	0.00296	0.9826	0.00341	1.0791	6.5%
201400	0.3012	1.0161	632	0.00296	0.9826	0.00338	1.0696	5.0%

Table 4: Comparison testing results with strain gage

Where: N – number of cycles

R_{csg} – Reaction reading of CSG® (miners rule application)

$U_{p\text{-}csg}$ – Accumulated fatigue value for CSG®

F_{limit} – Theoretical fatigue limit based on calculated strain values in combination with S-N curve data

$Strain_t$ – Theoretical strain

$U_{p\text{-}t}$ – Accumulated theoretical fatigue value for strain (miners rule application)

$Starin_A$ – Actual measured strain

$U_{p\text{-}g}$ – Accumulated fatigue value based on measured strain (miners rule application)

Conclusions

At the end of the DIR activity the overall assessment of the CSG® methodology can be made as fully satisfactory. The CSG® has proven its ability to accurately gather fatigue data and most significantly, prognosticate failure based on accumulated fatigue in the host structure. The project is now ready to continue to the next level of activities to further develop the technology and methodology for advanced applications, appropriate environmental situations, and final development of the optical reader device.

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13. **Abstract ……..**

Advanced Fatigue Measurement and Prediction System Suitable for Critical Defence and Aerospace Structures

As air platforms continue to evolve and increase in efficiency, new technologies are posed to contribute significantly to the evolution of emerging new generation air and space systems. Sensor technologies are posed to alter command and control, flight control, and maintenance functions and regimes. Additionally, due to its defence strategy and cost reduction implementation directive, the Royal Canadian Air Force is exploring alternatives to enhance the effectiveness of its aircraft life cycle management and maintenance approach.

This document reports on the development and demonstration of a new generation of life cycle fatigue sensor technology, known as chameleon Strain Gauge (CSG®) or fatigue accumulation sensor. The developed sensor demonstrated the ability to accurately and consistently measure structural fatigue, together with reliable prediction of remaining fatigue life using AL 6061-T6 and CS 4340 sample coupons. Such sensor capability not only met but surpassed set specifications and expectations.

The physical nature, low profile (e.g. stamp size), of the sensor makes it suitable for applications where information on the structural integrity is critical to airworthiness assurance of aircraft components (e.g. landing gears, wing spars, fuselage bulk head.) Improved data acquisition protocols and procedures are required to ensure technology exploitation effectiveness, particularly for critical hard and less accessible components.

Résumé

Les aéronefs sont en constante évolution et leur efficacité ne cesse de s'accroître. De nouvelles technologies qui contribuent de manière appréciable à l'évolution de la nouvelle génération de systèmes aériens et spatiaux sont donc développées. Des capteurs sont mis au point pour modifier les systèmes de commandement et de contrôle, les commandes de vol, ainsi que les tâches et les programmes de maintenance. De plus, en raison de sa stratégie de défense et de sa directive sur la mise en œuvre des mesures de réduction des coûts, l'Aviation royale canadienne explore différentes options en vue d'améliorer l'efficacité de ses méthodes de gestion du cycle de vie et de maintenance des aéronefs.

Le présent document traite de la mise au point et de la mise à l'essai d'une nouvelle génération de capteurs de fatigue pour l'analyse du cycle de vie connus sous le nom de Chameleon Strain Gauge (CSGMD) (extensomètre caméléon) ou capteurs d'accumulation de la fatigue. Le capteur mis au point a démontré sa capacité à mesurer avec précision et de façon uniforme la fatigue structurale et à prédire de manière fiable la durée de vie en fatigue restante à partir d'échantillons d'essai de AL 6061 T6 et CS 4340. Les capacités du capteur ont permis non seulement de respecter les spécifications et les attentes établies, elles les ont dépassées.

La composition physique du capteur et sa petite taille (de la grosseur d'un timbre) font en sorte qu'il convient à des applications pour lesquelles l'obtention de renseignements sur l'intégrité structurale est essentielle afin d'assurer la navigabilité des composants d'aéronef (p. ex. train d'atterrissage, longerons d'aile, cloisons de fuselage). Des procédures et des protocoles d'acquisition de données perfectionnés sont nécessaires afin d'exploiter avec efficacité la technologie, plus particulièrement en ce qui a trait aux composants essentiels qui sont difficiles d'accès.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS

Fatigue sensor; CSG sensor; fatigue accumulation sensor; optical sensor; reaming useful life; signal processing; life extension; aircraft maintenance; life cycle management.