"Structural Fatigue Monitoring, Modeling, and Prediction"

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Background & Significance

Structural integrity is critical to the success of everything from our transportation infrastructure to the aircraft and spacecraft that we count on to keep us safe. Whether flying to a nearby city, returning to the moon, or traveling to Mars and beyond, the structures that protect and transport us must remain structurally sound. Fatigue is a significant and complex phenomenon defined as the degradation of a material, primarily due to the formation of cracks resulting from repeated application of stress cycles. Fatigue contributes significantly to the damage and failure of metallic structures in particular. The importance of fatigue is accentuated by the fact that fatigue failures are often catastrophic and may occur without apparent visual warning.

This research works to develop and improve on current fatigue prediction models and generate recommendations for sensor placement to generate real-time data that will positively impact the safety and longevity of aircraft and spacecraft.

Project Goals

The proposed project goals were to:

1. Investigate component level fatigue prediction models and current system level health monitoring recommendations.
2. Design and run component level laboratory fatigue tests.
3. Interrogate laboratory test result data to develop or update fatigue prediction models.
4. Identify recommendations for minimalist sensor placement for real-time fatigue monitoring.

Note that due to the COVID-19 pandemic, efforts were taken to pivot away from physical laboratory fatigue tests in favor of model-based testing and analysis. At this time, laboratory test results from previously completed coupon level fatigue tests have been used to research fatigue prediction.

Summary of Key Findings

Extensive research into current fatigue analysis methods, component level fatigue prediction models, and current system-level structural health monitoring recommendations is ongoing. A compilation of relevant peer-reviewed journal articles and papers from conference proceedings have been reviewed and documented, both as the basis of a literature review and to shape the nature of this research going forward. In addition, significant time has been spent on understanding the analysis required to calculate fatigue life generally as well as the specific methodology and MATLAB coding used in previous aluminum coupon testing and analysis recently completed within the research group. Once fatigue as a phenomenon and fatigue analysis methods were better understood, a sensitivity analysis was completed. The sensitivity analysis was carried out to determine if and how changes to various material properties impact the fatigue life of metals broadly and aluminum specifically. Based on the completed sensitivity analysis, research efforts were focused on dynamic properties of the aluminum. The figure below shows how the damping and frequency of all coupons changed over the lifetime of each coupon. Note that coupon lifetimes have been normalized to better compare results across tests. This dynamic data can be extracted directly from structural system identification models based only on the acceleration applied to the coupon and the response of that coupon. Dynamic properties have not yet, as far as the author is aware, been researched as a critical means to understanding real-time fatigue in metallic structures in this manner. These are encouraging, if not yet definitive, results for which a paper is in work for publication. This research will continue throughout the upcoming academic year thanks to AY 2021-2022 funding from the Vermont Space Grant Consortium Graduate Fellowship Program.

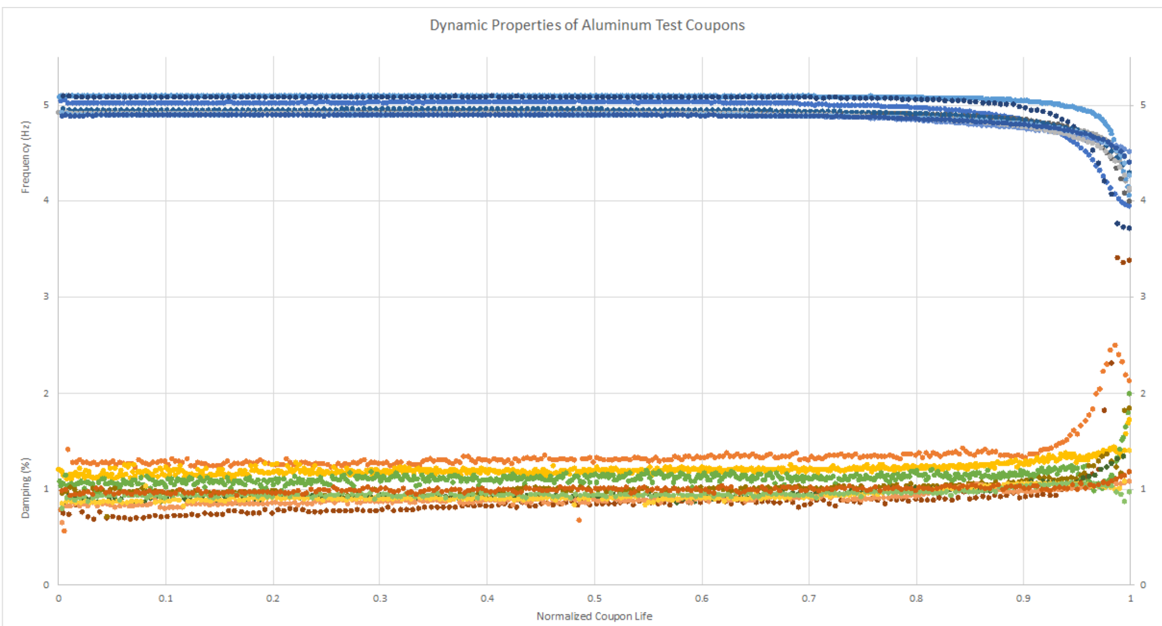

Figure 1. Dynamic properties over the life of aluminum test coupons subject to repeated stress cycles.