Objective
The objective of this work is to develop an experimental system capable of performing Electromechanical Impedance (EMI) based structural health monitoring in a structure operating under highly dynamic environment.

Introduction
Structural health monitoring (SHM) is a method for recognizing changes of state in structures used for civil, aeronautical, and mechanical applications [1]. A change of state is any variation to the physical/geometrical features of the system that adversely affects the system dynamic response, like mass, stiffness, and boundary conditions. SHM systems are capable of improving the safety of engineering structures, and reducing the associated maintenance expenses. Current SHM technology is suitable for detecting changes of state in slowly changing structures on the order of seconds to minutes. There is a growing need to advance this technology for structures operating in highly dynamic environments (e.g. shock, blast, high-velocity impact, etc.) to enable microsecond to millisecond detection. [2]. Examples of such structures are shown in Fig. 1.

Among different methods available for the application of SHM, the impedance measurement system (EMI) method is an attractive option since it employs piezoelectric (PZT) transducers, which are cheap, small-scale, and easily installable.

Methodology
Electromechanical Impedance Method
The electromechanical impedance (EMI) method utilizes the electromechanical coupling properties of piezoelectric materials (PZTs) to use them as both a sensor and an actuator simultaneously. [3] By bonding a PZT to a structure, the electrical impedance of the PZT becomes a function of the mechanical impedance of the host structure; therefore, changes in the mechanical structure are reflected in the electrical impedance of the PZT. This process is illustrated below in Fig. 2.

Results
Velocity Calibration
To calibrate the impact velocity of the striker as a function of the propellant gas pressure, the striker is launched at a constant velocity and the resulting impact velocities are recorded and averaged. The mean impact velocity results are plotted as a function of time (shown in Fig. 7). A quadratic curve fitting is applied to estimate the expected velocity for a given pressure. Thus, the system’s ability to produce custom, repeatable impact event is verified.

Dynamic System State Detection
A broadband frequency sweep (shown in Fig. 8) is done on the PZT in its undisturbed state to determine its sensitive frequency range. The sensitive frequencies are selected from 83.86 kHz, 84.10 kHz, and 84.54 kHz, and the PZT is excited at each of these single-tone frequencies while impacting the incident bar at 2.09 m/s velocity. Then, a multi-tone excitation signal is formed by adding these 3 frequencies, and the PZT is excited by this signal while being impacted at the same velocity. Fig. 9 shows the impedance results for both single and multi-tone signals.

Discussion
For both the single-tone and the multi-tonal cases, the impact causes a significant drop in the impedance values, which rises up again after the effects of impact are gone. Hence, the experimental system can detect dynamic state change under impact using the EMI method.

The post-impact impedance values are lower than the pre-impact impedance values. This can be attributed to a permanent change in the PZT and the incident bar. The impedance results for the multi-tonal signal match the results for the individual single-tone signals. Hence, instead of running separate impact tests for the single-tones, the same impedance data can be found by using only the multi-tonal signal. The reduction in the number of experiments significantly reduces the total measurement time.

Conclusions & Future Work
• The experimental system is able to create collisions between the moving striker bar and the static incident bar at different velocities.

• The impedance measurement system can continuously detect changes of state in the dynamic state of the cantilever incident beam under impact using both single-tone and multi-tonal excitations. To the best of the author’s knowledge, this research shows the first instance of experimental observation of change in impedance during a highly dynamic event.

• To facilitate microsecond-timescale operation, the existing DAQs need to be replaced with high-speed measurement devices like field-programmable gate arrays (FPGAs) with high sampling rate (>100 MS/s).

• Additional experiments need to be performed by changing the incident bar boundary conditions (free-free, simply supported), and striker bar dimension (different length and mass).

References

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