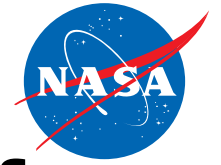

In-Line Electromagnetic Actuator for Fuel Modulation

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Outline

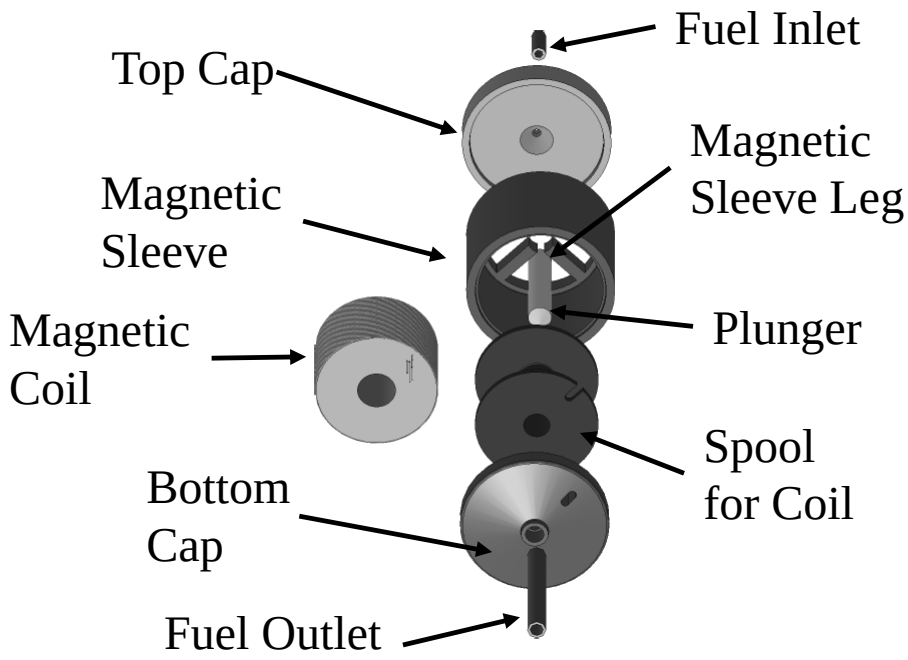
- Introduction
- In-Line Electromagnetic Actuator Description
- Test Setup and Conditions
- Test Results
- ILEM Testing – Increasing Excitation
- Discussion
- Conclusion & Future Work

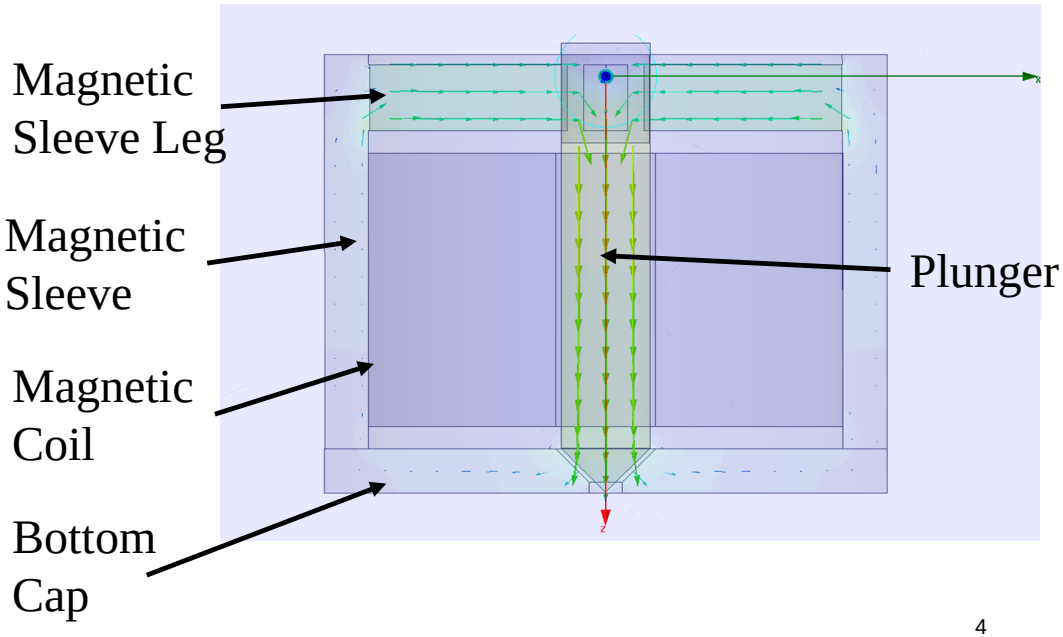
Introduction

- Demand for Lower Emissions (LE) in Aircraft Gas-Turbine Engines – Lean Burn (LB).
- LB/LE combustors susceptible to thermo-acoustic instabilities.
- Utilize fuel modulating actuators to actively control instabilities.
- In-Line Electromagnetic Actuator (ILEM) fuel modulator conceptualized, prototype fabricated, and tested.
- ILEM fuel modulator tested up to 1.2 kHz with input fuel pressure of ~300 psia.

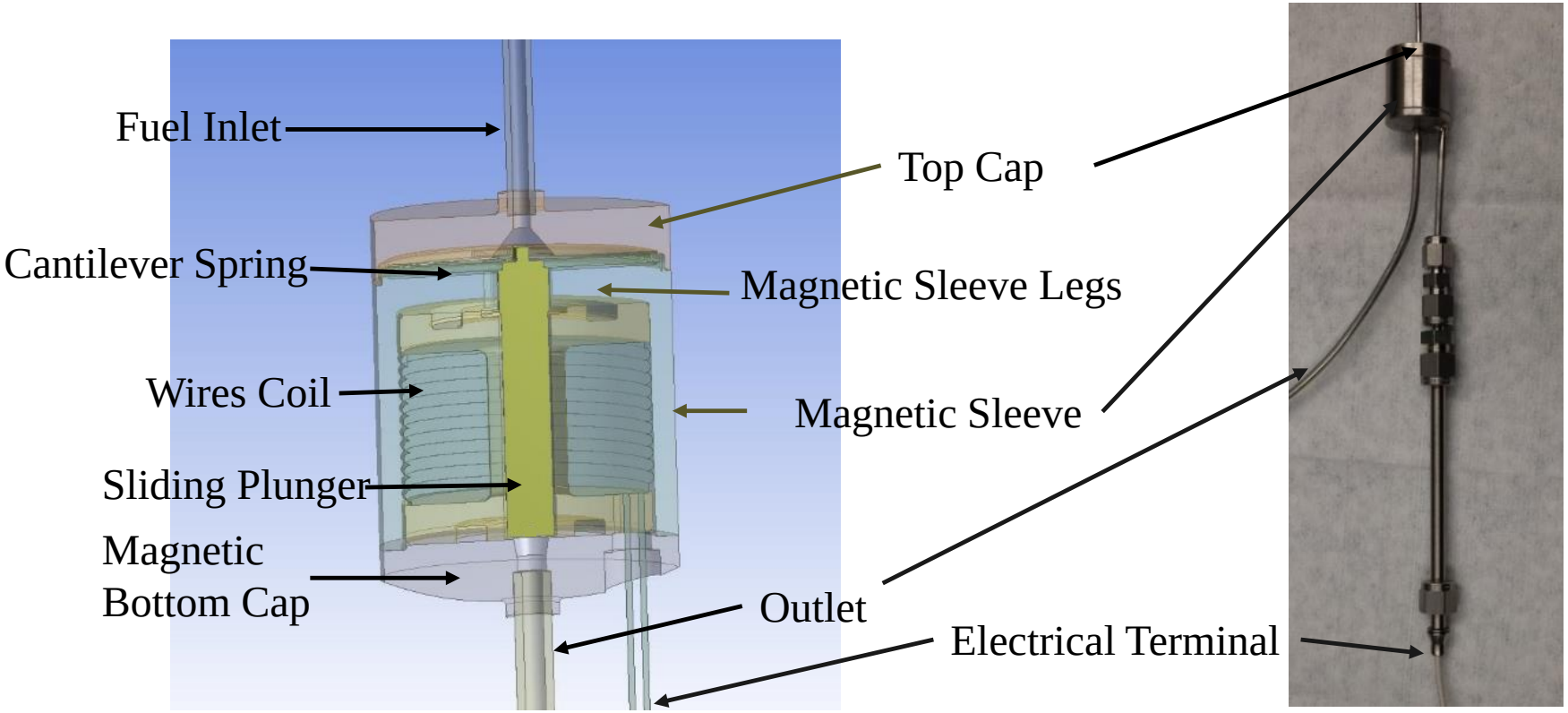
ILEM Fuel Modulator Description

- Normally open valve design.
- Magnetically actuated.
- Magnetic circuit- plunger moves to close valve when current applied to coil in order to minimize energy in the system.
- As plunger moves towards bottom cap valve closes partially.



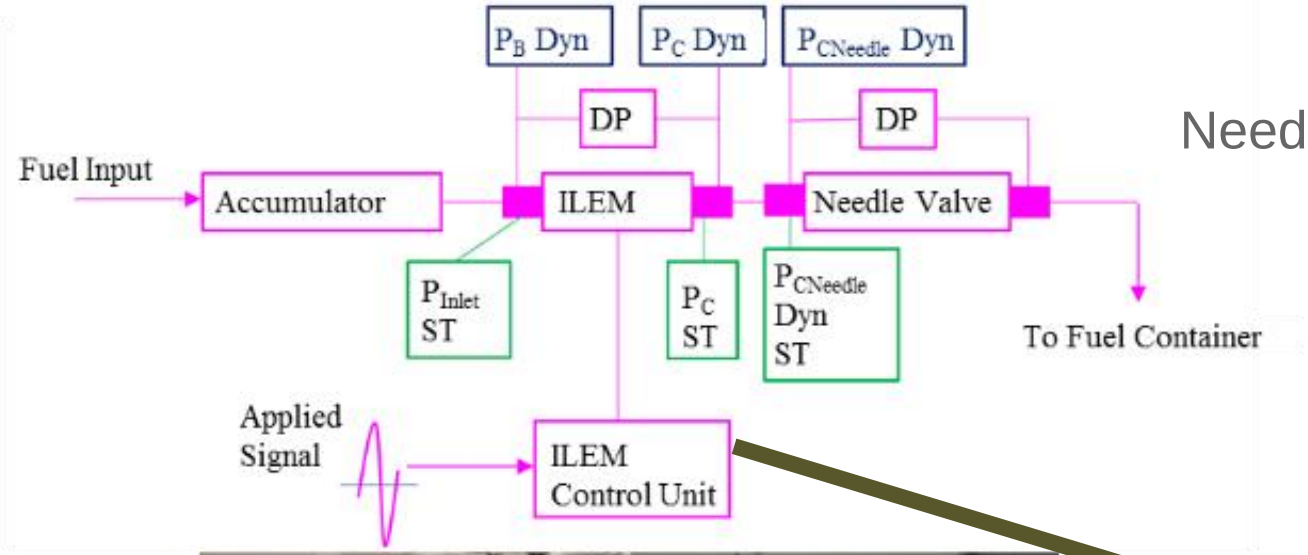


ILEM Fuel Modulator Prototype

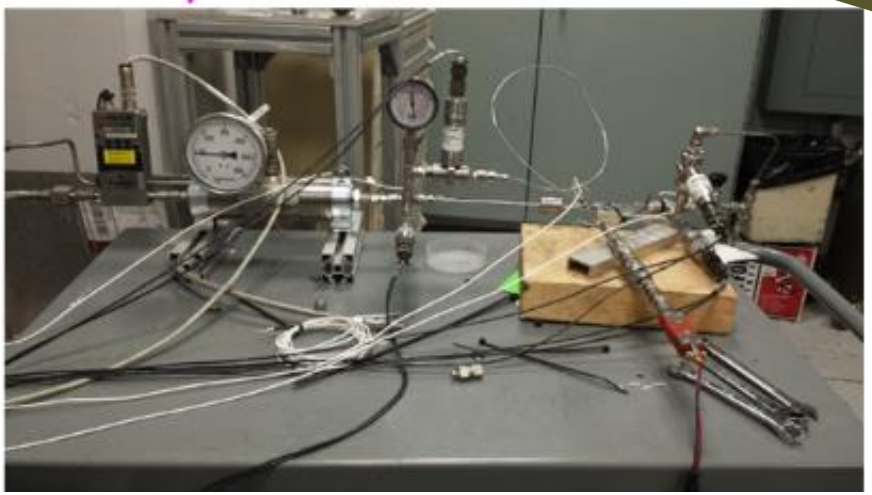


Test Setup

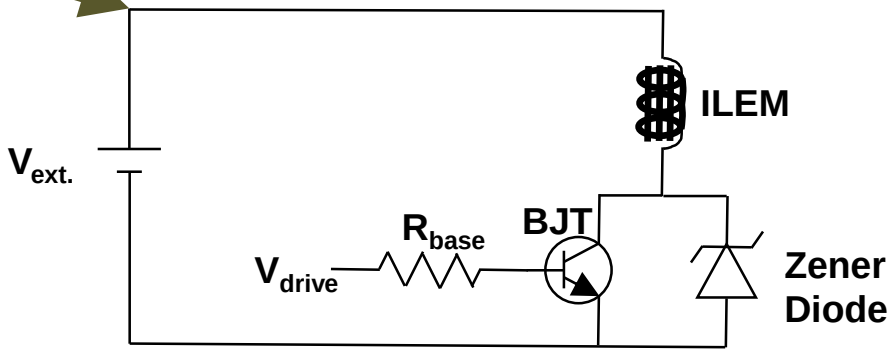
- Bench top tested using jet fuel.



Needle valve simulates injector



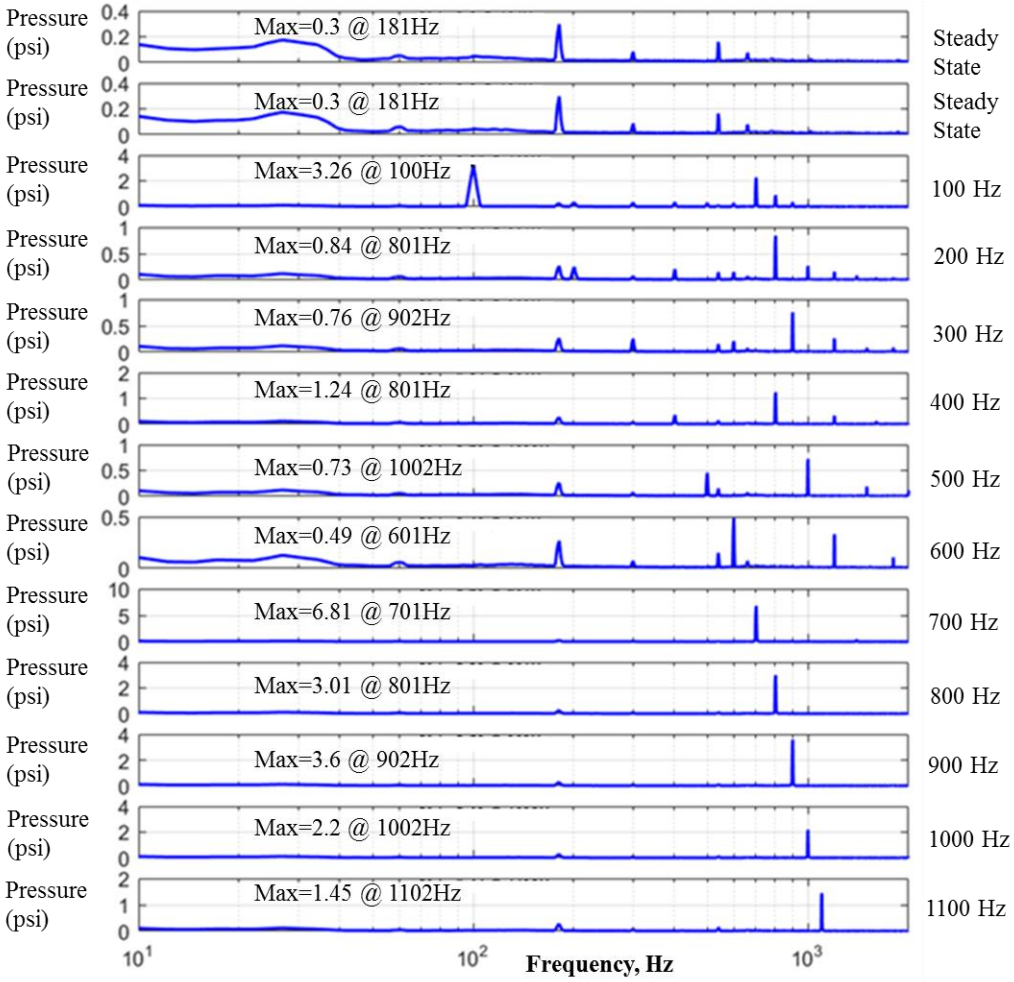
ILEM Control Unit

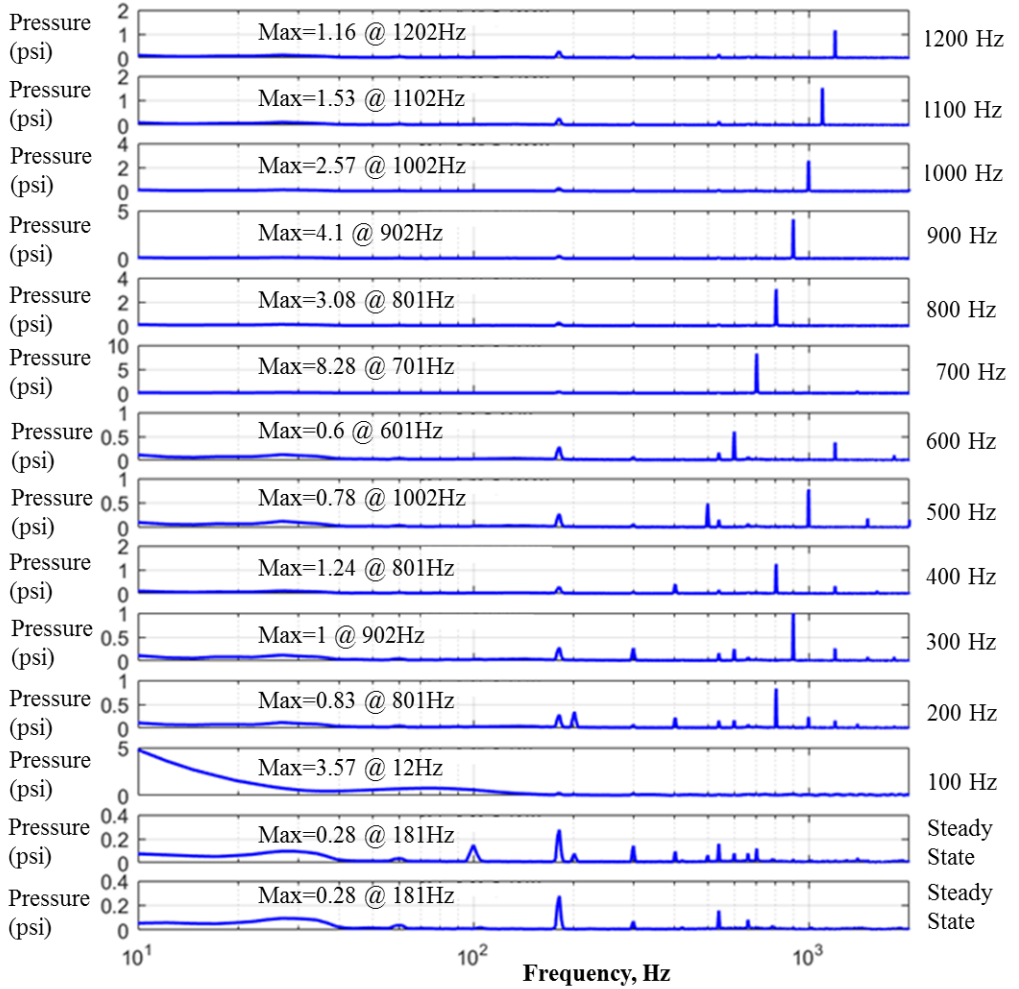


Test Conditions

- 300 psia inlet to ILEM
- Flow rate ~43 pounds per hour (PPH)
- Steady state measurements taken followed by measurements with the ILEM being driven from 100 Hz to 1200 Hz back to 100 Hz, in 100 Hz increments.
- Power supply voltage to the ILEM control unit circuit set at V_{ext} = 4 V, V_{drive} = 8 V peak-to-peak.

Test Results





180 Hz noise distortion at lower frequencies

Test Results Continued

Frequency (Hz) ↑	P_C Dyn (PSI)	$P_{CNeedle}$ Dyn	Frequency (Hz)↓	P_C Dyn (PSI)	$P_{CNeedle}$ Dyn
100	3.26	NA	100	NA	NA
200	NA	0.71	200	NA	0.93
600	0.49	NA	600	0.60	NA
700	**6.81**	NA	**700**	**8.28**	NA
800	**3.01**	NA	**800**	**3.08**	NA
900	**3.6**	**0.45**	**900**	**4.10**	**0.46**
1000	2.2	0.63	1000	2.57	0.64
1100	1.45	1.29	1100	1.53	1.45
1200	1.16	NA	1200	1.16	NA

Actuator Flow Number= ≈15.00
Needle Valve Flow Number= ≈2.50

Increasing Excitation Voltage

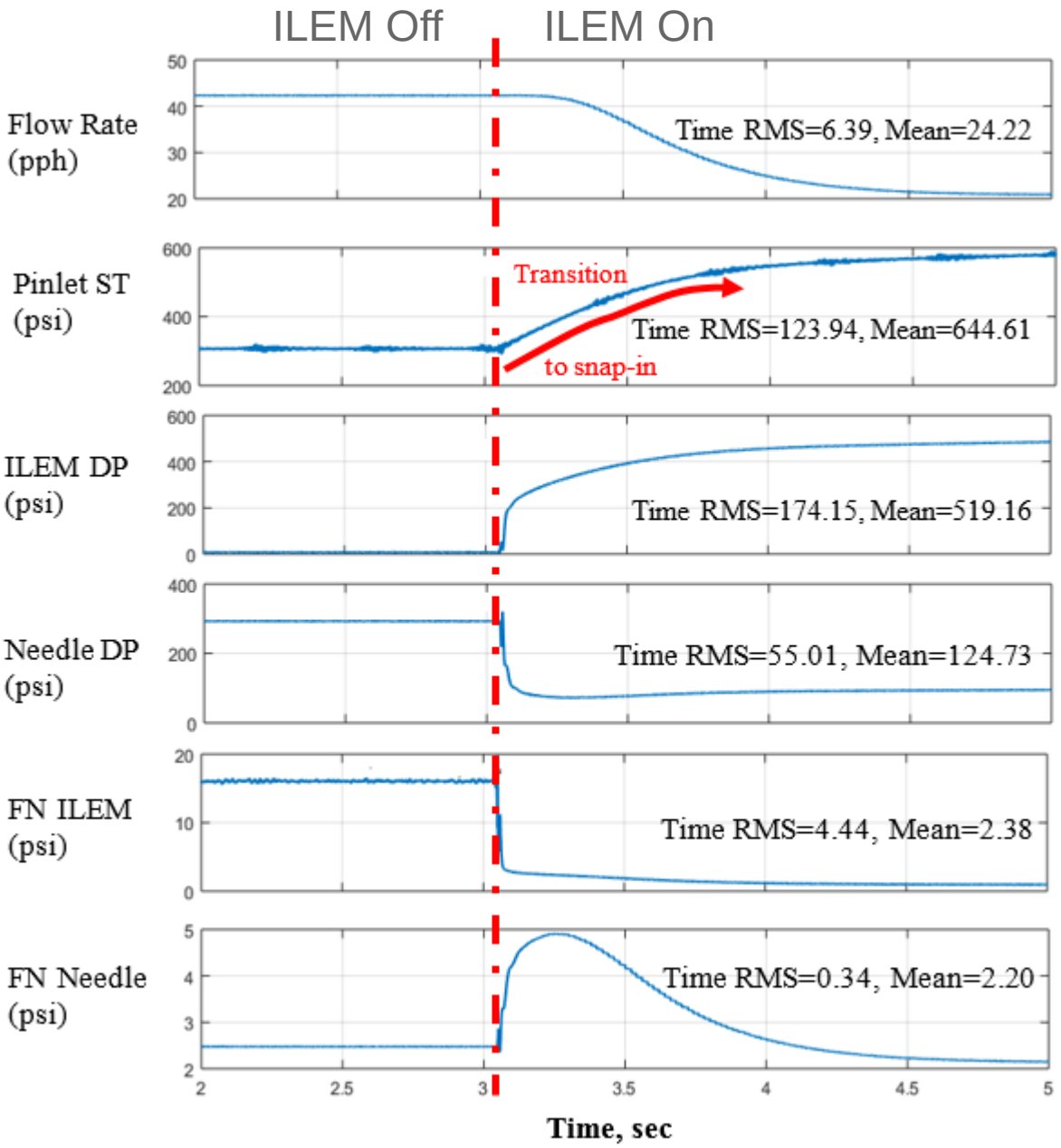
Goal: Increase the drive voltage to bring the plunger closer to the bottom cap and increase differential pressure (lower FN).

- Power supply voltage to the ILEM control unit circuit set at V_{ext} = 4.5 V, V_{drive} = 8 V peak-to-peak.
- Same inlet pressure and flow rate as multi-frequency testing above. (300 psia / 43 PPH)
- **Observation:** at lower frequencies the plunger would come in contact with the bottom cap – electromagnetic snap-in.
- Electromagnetic snap-in due to nonlinear electromagnetic force relation to the gap spacing vs linear restoring force from spring tethered to plunger:

$$F \propto \frac{\mu_o A (NI)^2}{gap^2}$$

- When snap-in occurs the plunger is in intimate contact with the bottom cap – restricting flow.

Effect of Snap-In Phenomena



Discussion

- Achieved primary goal of demonstrating functional capabilities of ILEM actuator to modulate fuel at various frequencies.
- Optimum performance of the ILEM actuator was demonstrated from 600 Hz to 1200 Hz.
- Noise prevalent in system at 180 Hz, possibly coupling noise from the grid power.
- Below 600 Hz measured modulation was not strong enough to overcome noise in the system.

Discussion-2

- Settings for the ILEM control unit circuit have yet to be optimized.
- Test results presented above were taken with conservative drive voltages to ensure a complete set of data could be captured in limited test time.
- Initial explorations of higher drive voltages indicate full capability of the ILEM modulator untapped.

Discussion-3

- Snap-in phenomenon demonstrates the electronics drive parameters can be further optimized.
- Minor modifications to design can improve performance and eliminate pull-in phenomenon
    - » Add a non-magnetic spacer to the tip of the plunger.
- Snap-in phenomenon indicates ILEM modulator is tunable for different flow numbers.
    - » Apply a DC current to the magnetic coil to bias the DC position of the plunger.

Conclusions & Future Work

- Demonstrated electromagnetic fuel modulator design capable of fuel modulation from 600 to 1200 Hz.
- Best response occurs near 600-700 Hz.
- Still a lot of room to improve performance by adjusting drive control electronics parameters.
- Future work will include optimizing drive voltages to increase differential pressure at ILEM outlet.
- Future work will explore variable tuning for desired flow number via application of DC current to preset plunger position.
- Non-magnetic spacer to be added to the plunger tip to prevent snap-in at lower frequencies.

Acknowledgements

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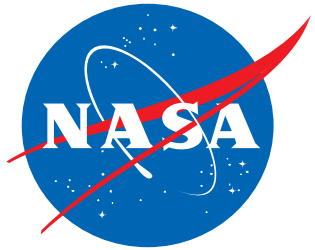
- We thank the staff of the Technical Services Branch for fabrication and the staff of the Combustion Branch for preparing the benchtop test stand.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