



Assessment of Model-Based Control for an Aircraft Engine Simulation using an Optimal Tuner Approach

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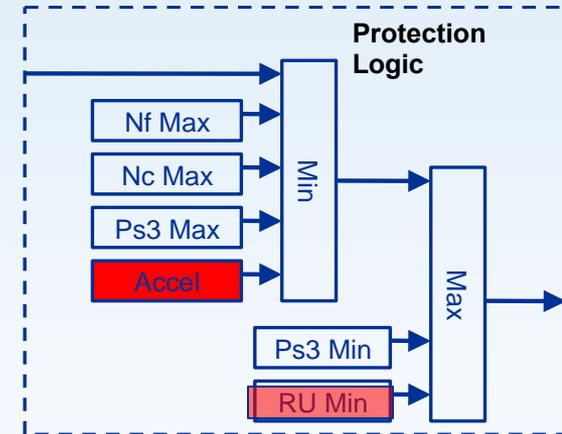
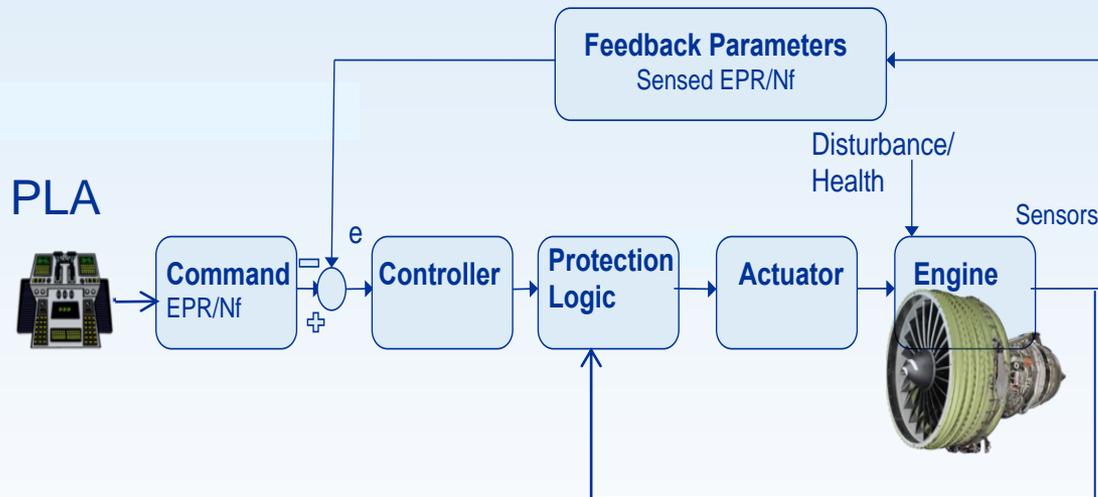


Model-Based Engine Control Overview

- Model-Based Engine Control (MBEC) is a method of using an on-board model to estimate the desired control parameters, such as thrust and stall margin
- MBEC Concept has been around since early 1990s
 - The challenge has been model accuracy over engine life cycle
 - The approach here is to apply an Optimal Tuner Kalman Filter (OTKF) to serve as the on-board model
- MBEC is being developed as one of the advanced engine control system methodologies to improve turbofan engine performance, safety, and efficiency.

Current Engine Control Architecture

Full Authority Digital Engine Control



- Thrust cannot be measured and hence is indirectly controlled through regulating a measured variable which correlates with thrust e.g., Fan Speed, Engine Pressure Ratio (EPR).
- Stall Margins (SM) cannot be measured. Safe margins are indirectly maintained by acceleration and deceleration limits.
- Nominal operating line is conservative to maintain life cycle safety margins.



Motivation

- The Vehicle Systems Safety Technologies Project is investigating risk factors for operating the engine beyond its standard design to improve control during emergency situations.
 - MBEC offers a means to directly estimate the available margin during emergency situations
- MBEC is an ideal technology for incorporating diagnostic and prognostic research initiatives which will allow for greater autonomy of the engine.
- The estimation of the stall margin can allow for a larger operating envelope of the engine during the design phase to improve efficiency.



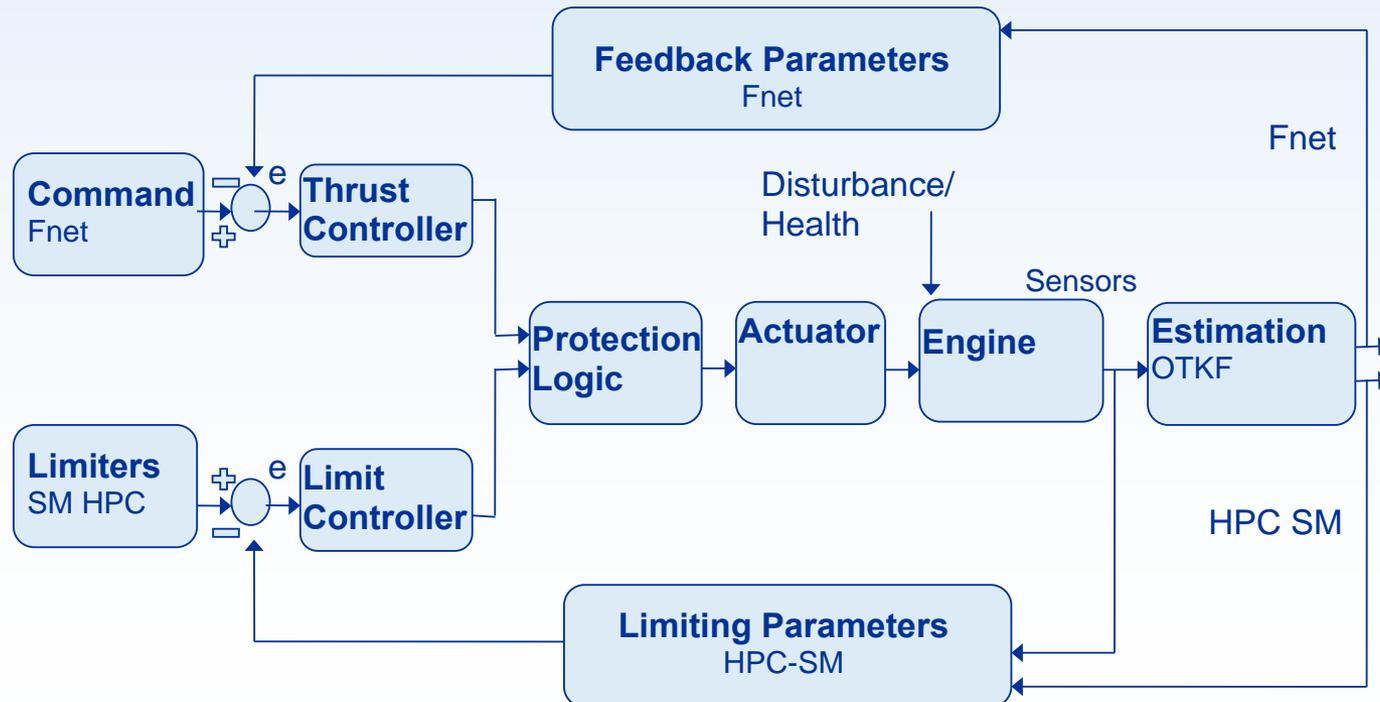
Modeling Application Approach

- A MBEC architecture is comprised of three main components
 - An engine or “truth” model.
 - An on-board model designed to provide real-time estimates of desired unmeasured parameters.
 - New controller and limit protection logic.
- Modeling approach to develop a MBEC architecture:
 - Modify the truth model to develop new control laws and allow for switching between the baseline and MBEC
 - Modify the on-board model, OTKF, to incorporate command signals and output the desired un-sensed parameters
 - Develop the Kalman Filter using a piece-wise linear model of CMAPSS40k
 - Integrate the OTKF with CMAPSS40k to calculate and verify the un-sensed parameter estimation



MBEC Architecture

- The approach is to use an on-board model of the engine to provide accurate estimates of un-sensed parameters that are used in the control system design.
 - If MBEC is proven to provide accurate estimates of safety parameters the required margins can be reduced.





Cruise Estimation Results

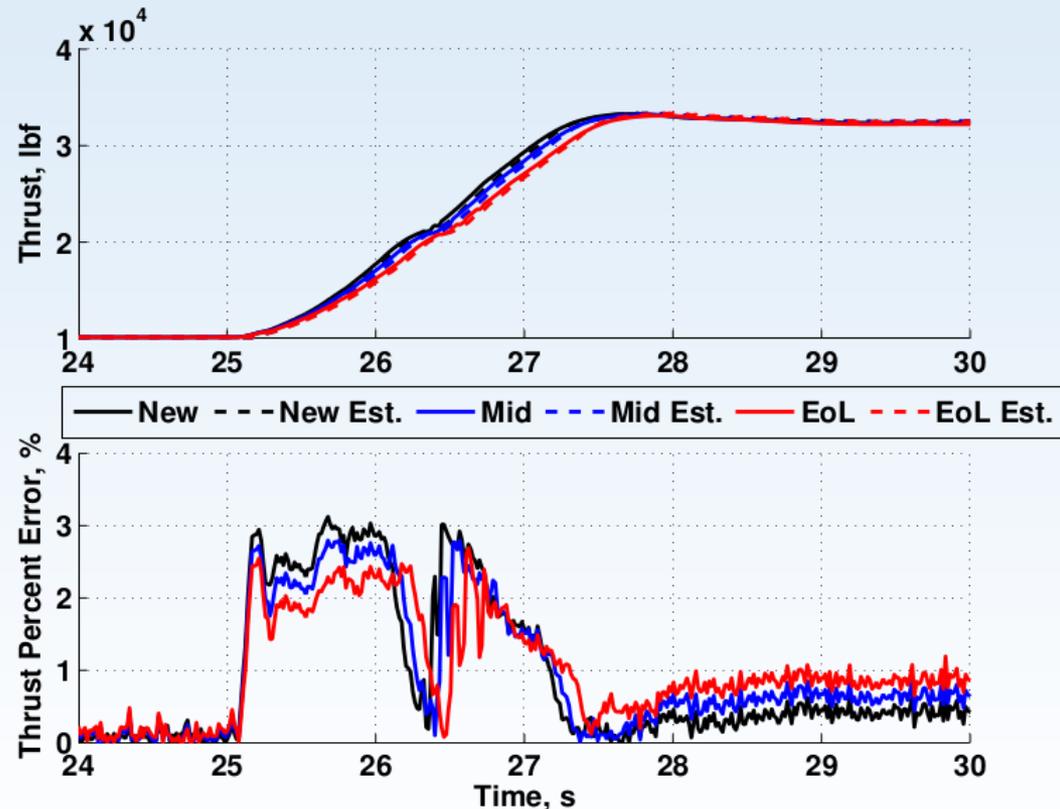
- Condition: Altitude of 30,000ft, Mach 0.7, PLA of 60° steps of +/-10°
 - Performance deterioration throughout the engine's lifecycle is simulated
 - The HPC SM regulator is designed to limit the HPC SM from falling below 11%, which accounts for the the non-transient HPC SM stack up
 - An aspect of designing the engine protection logic is guarding against high gas temperatures feeding into the turbine, T40.

Percent error	Net Thrust	HPC SM	T40
Average	<1.0%	<4.0%	<0.5%
Max	1.51%	5.9%	0.8%



Net Thrust Estimation Results: Takeoff

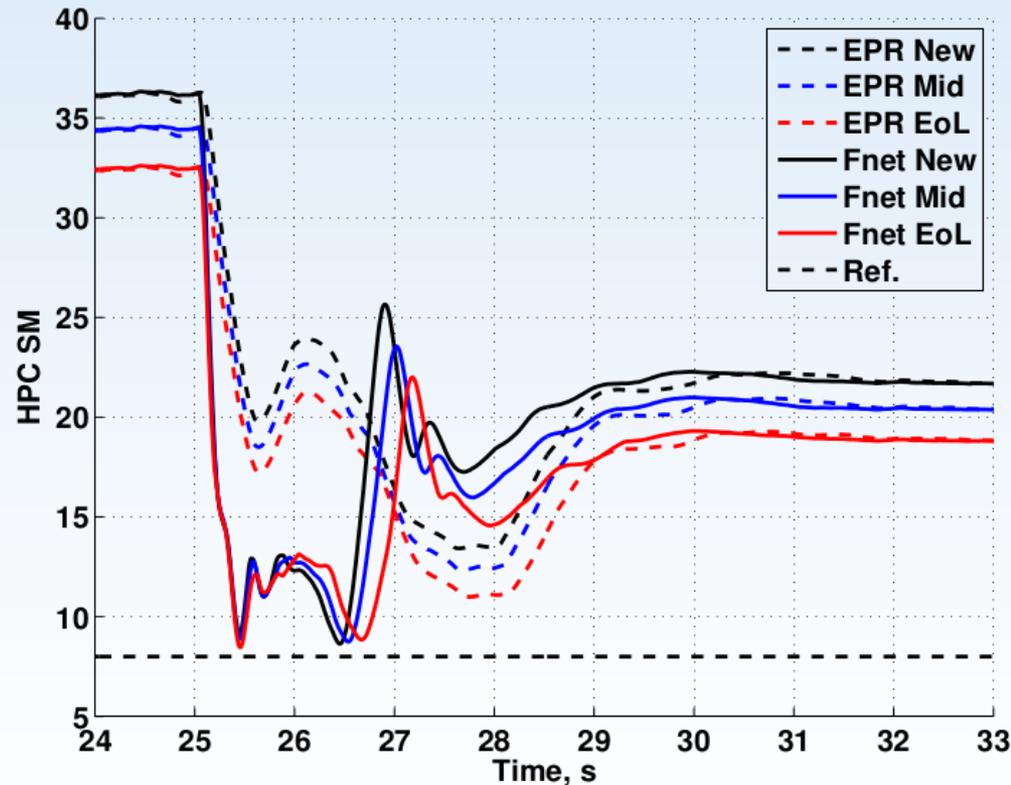
- Condition: FAA regulation to go from flight idle at sea level to 95% power in less than 5 seconds
- Similar estimation performance to the cruise condition is shown, however the largest estimation error has now increased to approximately 3% due to the very large transient.





Protection Logic: Stall Margin versus Acceleration Limiter

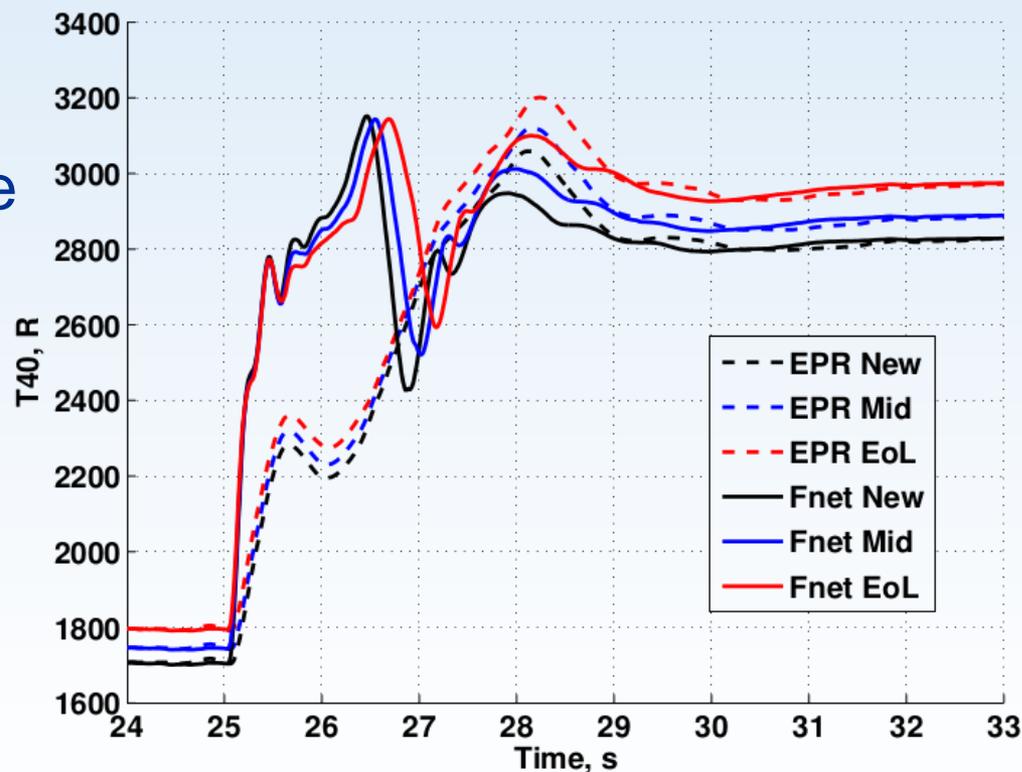
- Condition: Sea level static idle to full power transient to engage the protection logic
 - Comparison between the MBEC protection logic using the estimate of the HPC SM and the baseline CMAPSS40k EPR controller using an acceleration limiter
- Acceleration regulator designed to 11% SM, while the HPC SM regulator designed to 8% SM





Protection Logic: Stall Margin versus Acceleration Limiter

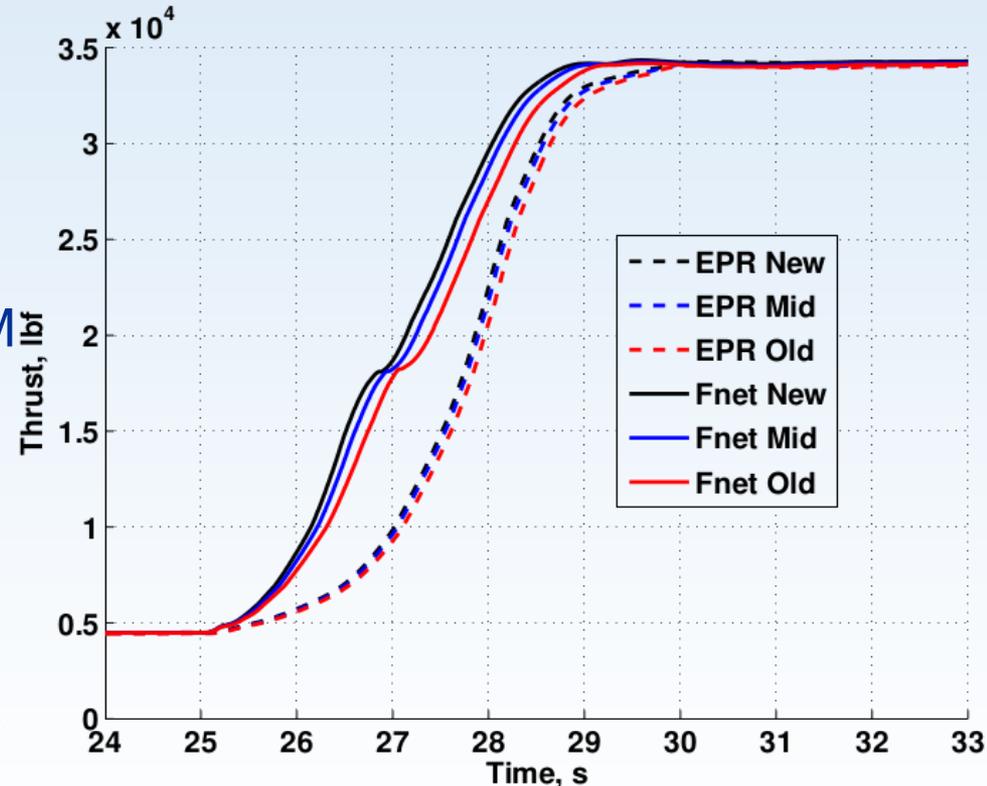
- The SM threshold was lowered to a value of 8% to prevent the MBEC design from having a higher max T40 than the baseline.
- This also accounts for uncertainty in the estimation of SM during the large transient





Protection Logic: Stall Margin versus Acceleration Limiter

- The MBEC control limiter has a significant response time advantage over the baseline controller using the acceleration limiter
 - A tight control of the HPC SM is a key potential benefit of the MBEC control design approach.
 - The significance of this, beyond a faster large transient response, would be for the operating line of the engine to be allowed to move to a more efficient regime of the operating envelope.





Conclusions and Future Work

- Development of a MBEC model utilizing CMAPSS40k and an optimal tuner Kalman Filter as the on-board estimation method.
 - Focusing on a thrust feedback and HPC stall margin limit logic MBEC architecture
- The MBEC architecture results show:
 - An improvement over an acceleration limiter in engine performance was shown, and thus could allow for more efficient engine operation by opening up new regions of the compressor map for operation
- Future analysis is investigating the potential of MBEC to open up a larger operating envelope of the engine to improve efficiency in the design phase, and applications to enhanced performance to prevent loss of control.



Questions?