



Hybrid Electric Aircraft with Unlike Engine Degradation

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Background

- Net-zero emissions economy by 2050
- USA developing new more-sustainable power and propulsion architectures
- Hybrid-electric may provide benefits in the near term
- Electrifying turbomachinery leads to new opportunities for control



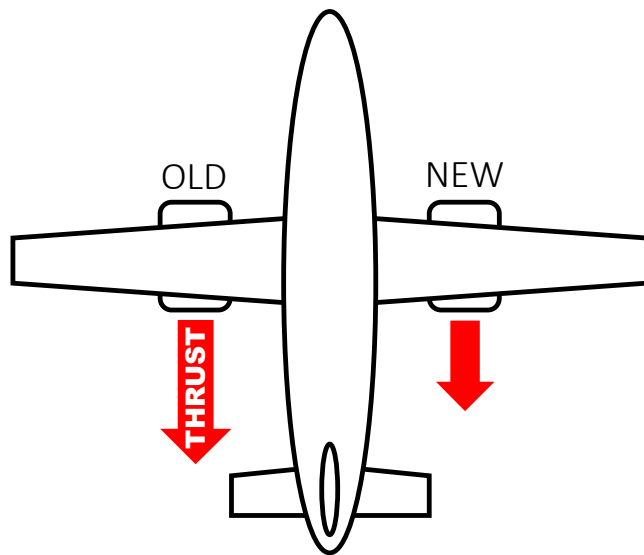
Subsonic Single Aft Engine (SUSAN)
Credit: NASA



Electrified Powertrain Flight Demonstration (EPFD)
Credit: NASA



Problem: Asymmetric Thrust

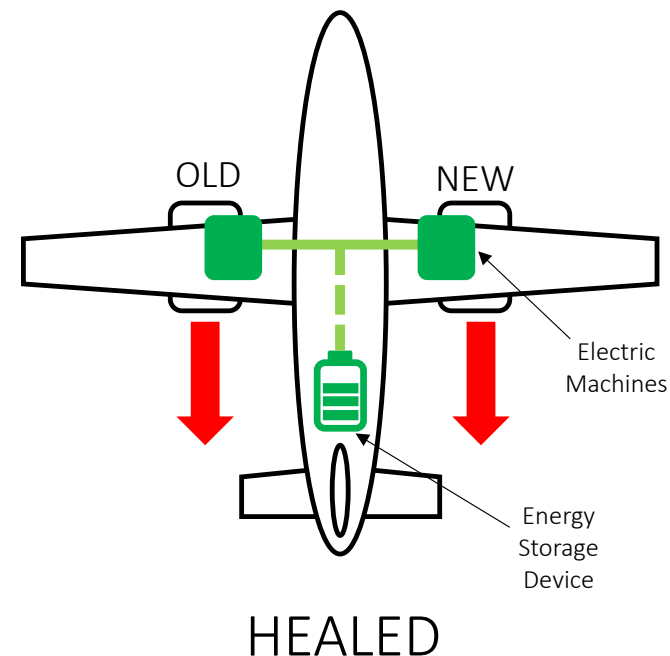


- Multi-engine aircraft with different levels of degradation
- Asymmetric degradation leads to asymmetric thrust
- Propulsion control based on corrected fan speed
- A degraded engine will produce more thrust at the same throttle setting
- Alter the control methodology?



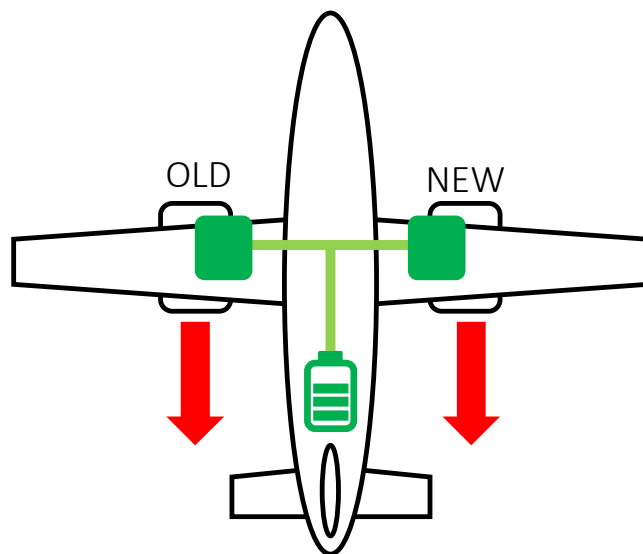
Solution: HEALED

- Hybrid Electric Aircraft with unLike Engine Degradation (HEALED) control
- Assuming an already hybrid-electric aircraft
- Electric machines extract or insert power in such a way that assists the degraded engine with power from the healthier engine or from an onboard power supply
- Later compared with alternative control methods

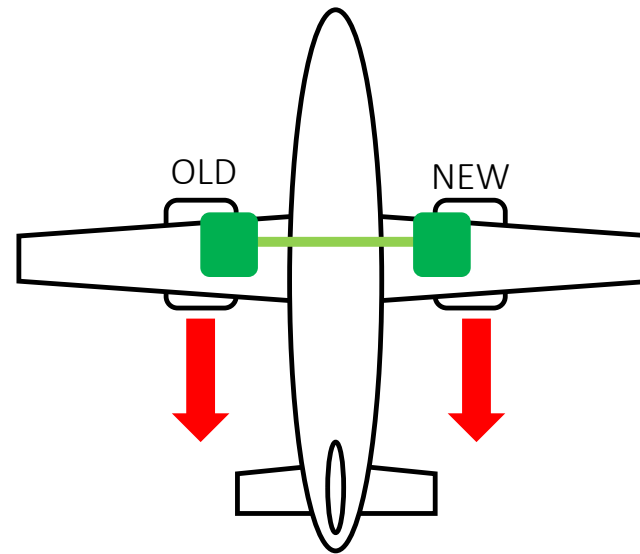




Methods of Energy Management



HEALED
With Energy Storage
Device

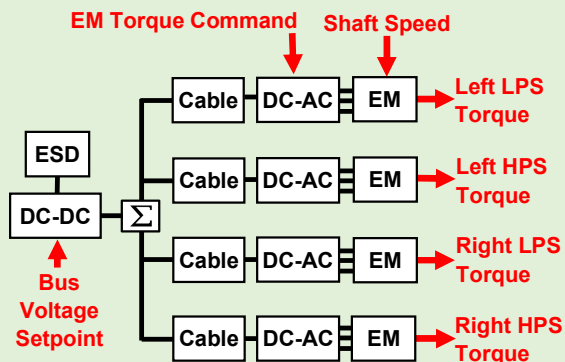


HEALED
With Power Transfer

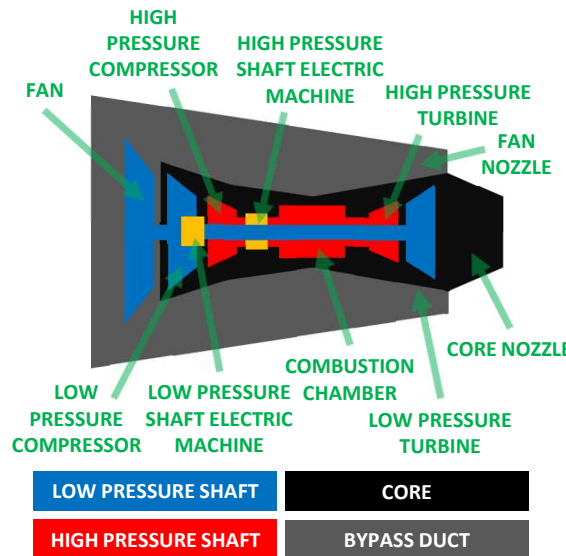


System Models

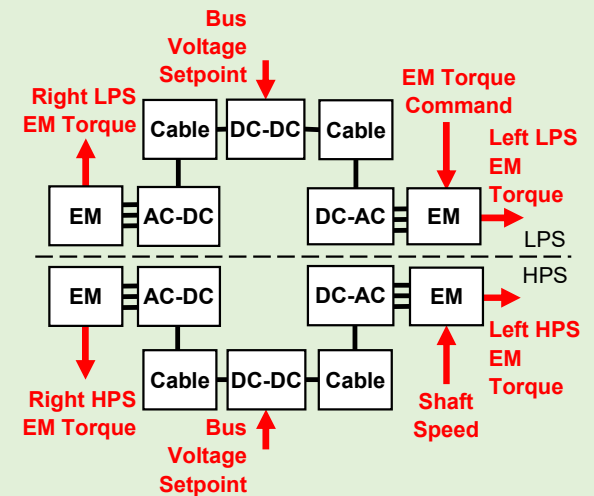
<https://github.com/nasa/emtat>
<https://github.com/nasa/t-mats>
<https://github.com/nasa/agt30>



Electrical Power System:
HEALED with Energy Storage



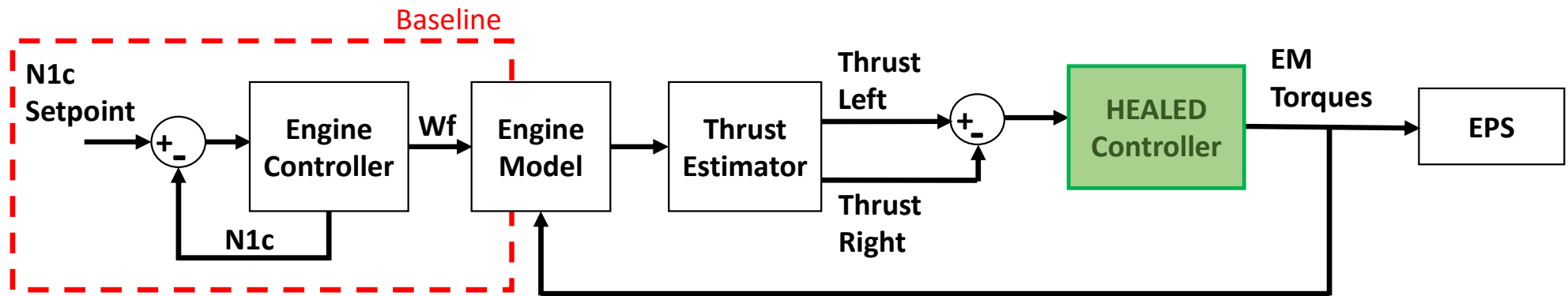
Conceptual Turbofan Engine



Electrical Power System:
HEALED with Power Transfer

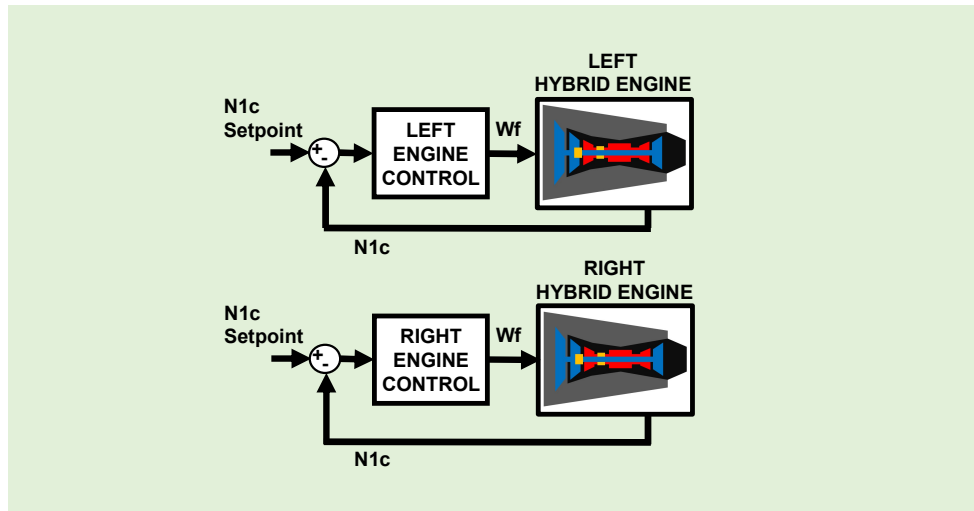


HEALED Control



- Augments the corrected fan speed (N1c) baseline engine controller
- Thrust estimation via Kalman Filter
- Sends torque commands to the electrical power system (EPS)
- Compatible with other power management control efforts
- The more-degraded engine is assisted by the coupled electric machines

Comparison with HEALED



Baseline Engine Control

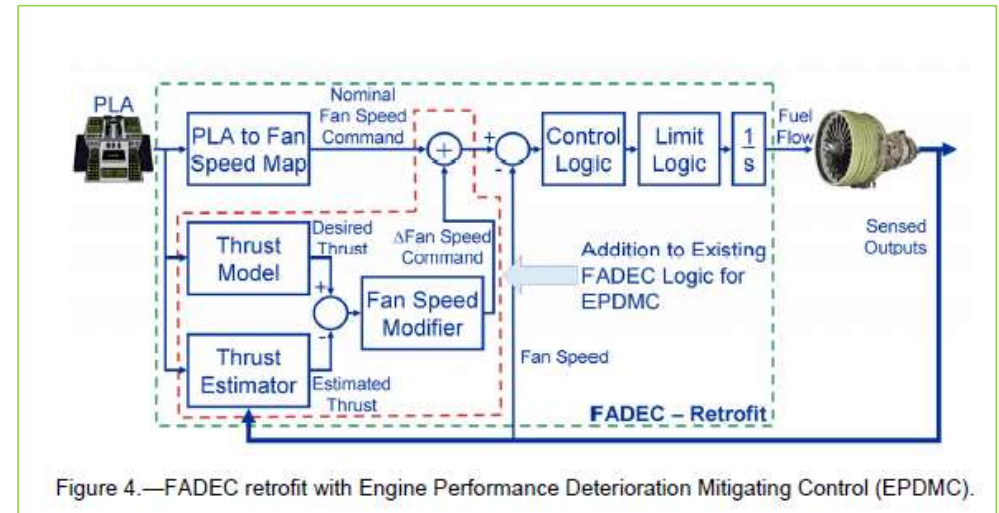


Figure 4.—FADEC retrofit with Engine Performance Deterioration Mitigating Control (EPDMC).

Engine Performance
Deterioration Mitigating Control
(EPDMC)¹

¹Litt, J., Sowers, T., and Garg, S. "A Retro-Fit Control Architecture to Maintain Engine Performance with Usage." 18th International Society for Airbreathing Engines Conference, Beijing, China, September 2007. <https://ntrs.nasa.gov/api/citations/20070032926/downloads/20070032926.pdf>

Results

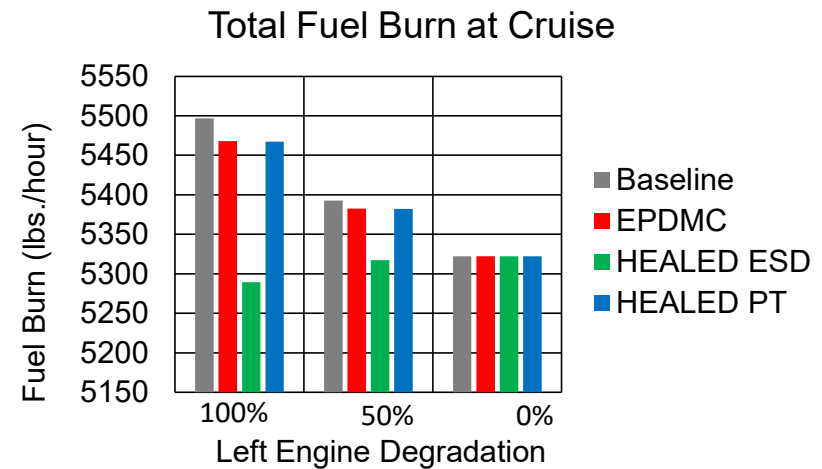
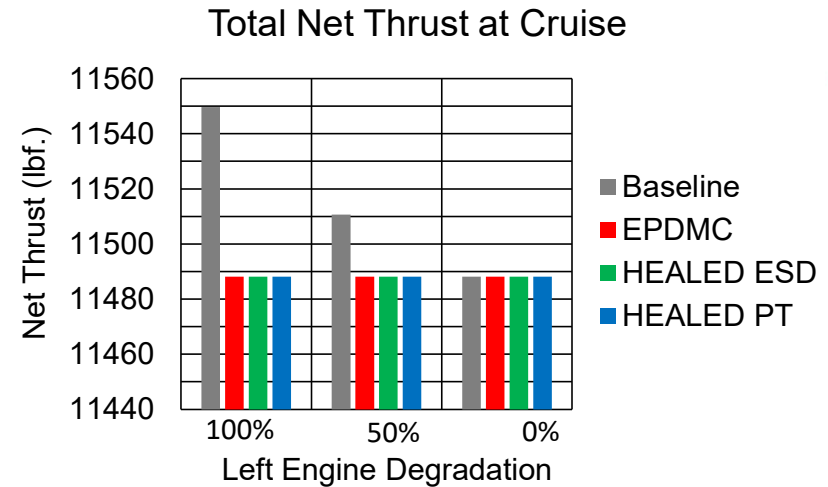


	Left Engine Degradation [%]	Total Fuel Burn [lbs./hour]	Total Net Thrust [lbf.]
Baseline	0	5322	11488
	50	5393	11511
	100	5497	11550
EPDMC	0	5322	11488
	50	5382	11488
	100	5468	11488
HEALED with ESD	0	5322	11488
	50	5317	11488
	100	5290	11488
HEALED With PT	0	5322	11488
	50	5382	11488
	100	5467	11488

ESD = Energy Storage Device

PT = Power Transfer

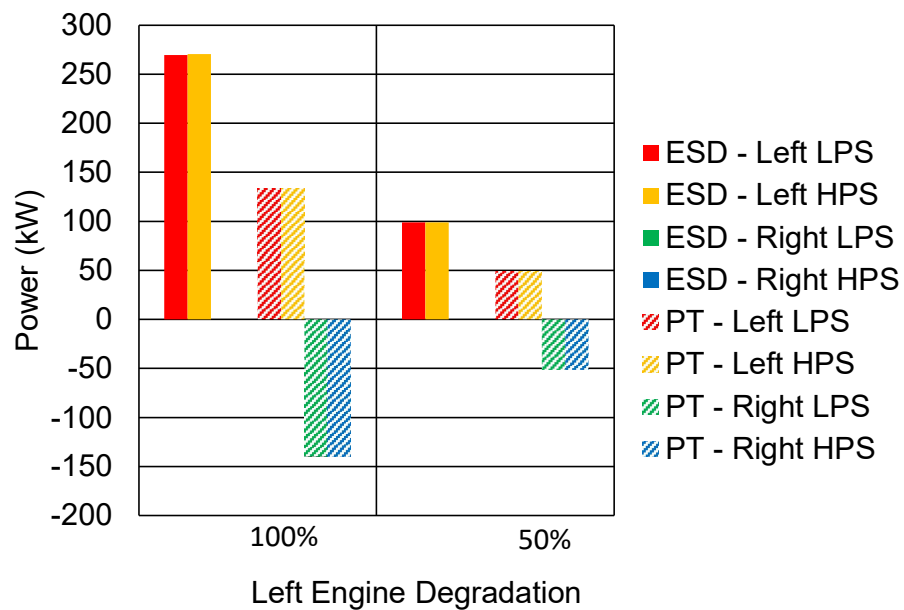
EPDMC = Engine Performance Deterioration Mitigating Controller





More Results

HEALED EM Power at Cruise



	Left Engine Degradation [%]	Battery Power [kW]*	EM Power Extraction [kW]*	EM Power Insertion [kW]*
HEALED with ESD	0	0	0	0
	50	210	0	198
	100	575	0	540
HEALED with PT	0	0	0	0
	50	0	103	99
	100	0	279	267

*Constant and continuous power required



Conclusion

- HEALED eliminated asymmetric thrust due to unlike engine degradation by assisting engine shafts with torque from electric machines.
- Instead of increasing fuel flow, HEALED assisted the more-degraded engine with electrical power.
- Uncertainties like weight penalties and thrust estimation should be investigated further.
- Hybrid-electric systems are not justified by HEALED only.
- HEALED could lead to reduced fuel consumption in hybrid-electric aircraft.



Acknowledgements

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