Exploration of the Versatile Electrically Augmented Turbine Engine Gearbox Concept

Jonathan Kratz and Dennis Culley

NASA Glenn Research Center (GRC)

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Motivation

Electrified Aircraft Propulsion (EAP)

More Electric Engines

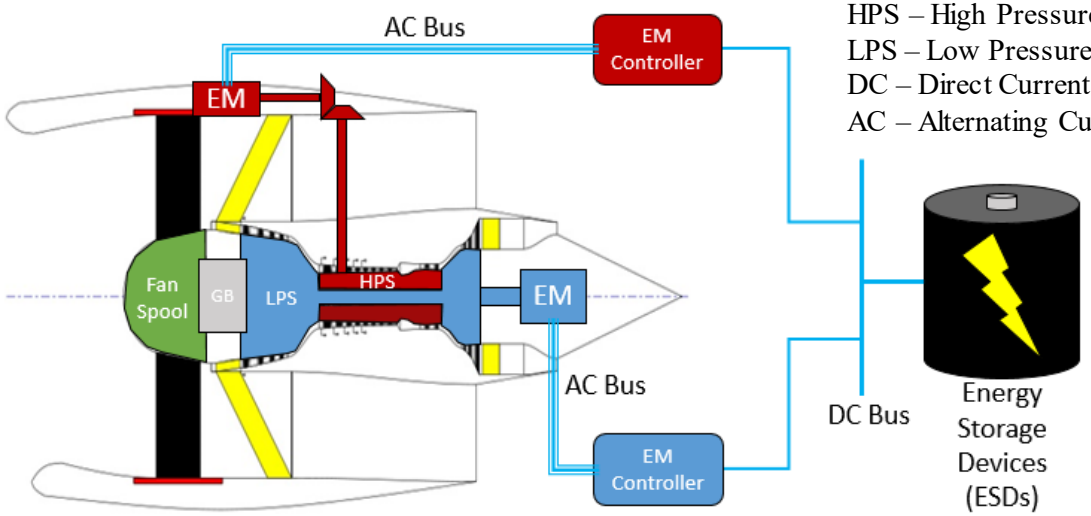
Engine Operability Control – Turbine Electrified Energy Management (TEEM)

Need to interface EMs of significant size with gas turbine engines

How can EMs be synergistically interfaced with gas turbine, allowing the EMs to be better leveraged?

Hybrid Electric Propulsion Concepts (Ex. STARC-ABL)

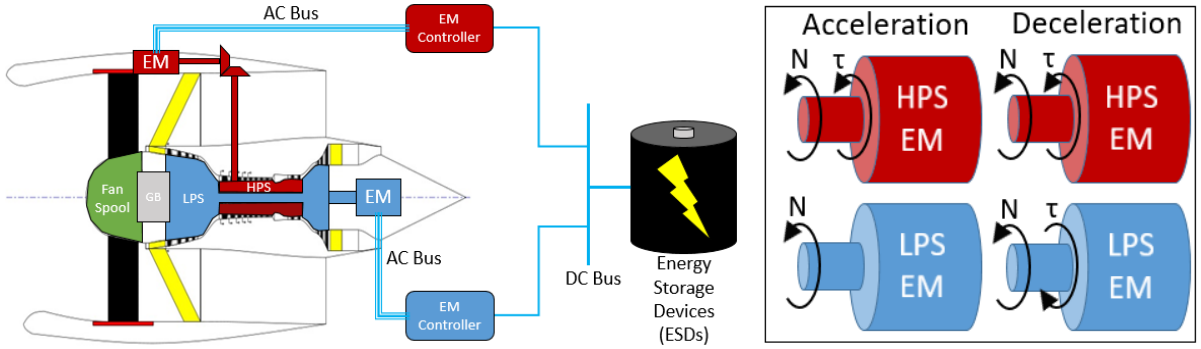
EM – Electric Machine
GB – Gearbox
HPS – High Pressure Spool
LPS – Low Pressure Spool
DC – Direct Current
AC – Alternating Current



More Electrified Engine with Implementation of TEEM

Background

TEEM



- Leverages EMs and energy storage to improve engine operability
  - Particularly during transients
  - Alleviates constraints on the engine design to achieve better performance
- Dedicated EM (DEM) approach:
  - Each EM can only directly impact their respective spools
  - Accelerations: Use the HPS EM to add power to the HPS
  - Decelerations: Use the LPS EM to extract power from the LPS and use the HPS EM to apply any excess power to the HPS

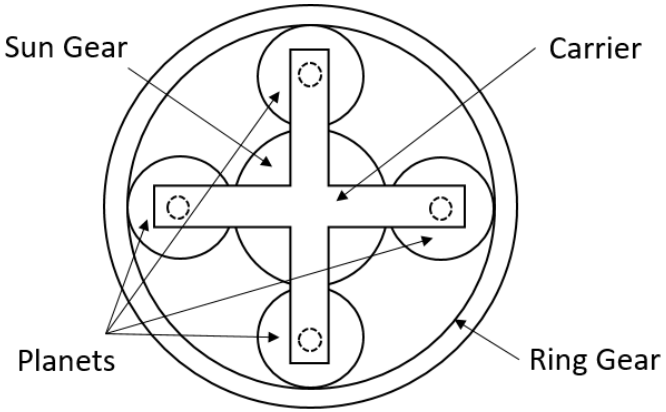
Power Extraction

- Desire to extract large amounts of power from the engine to drive strategically placed propulsors
  - Reduces drag while producing thrust
- Favors power extraction by can disproportionately favor one spool

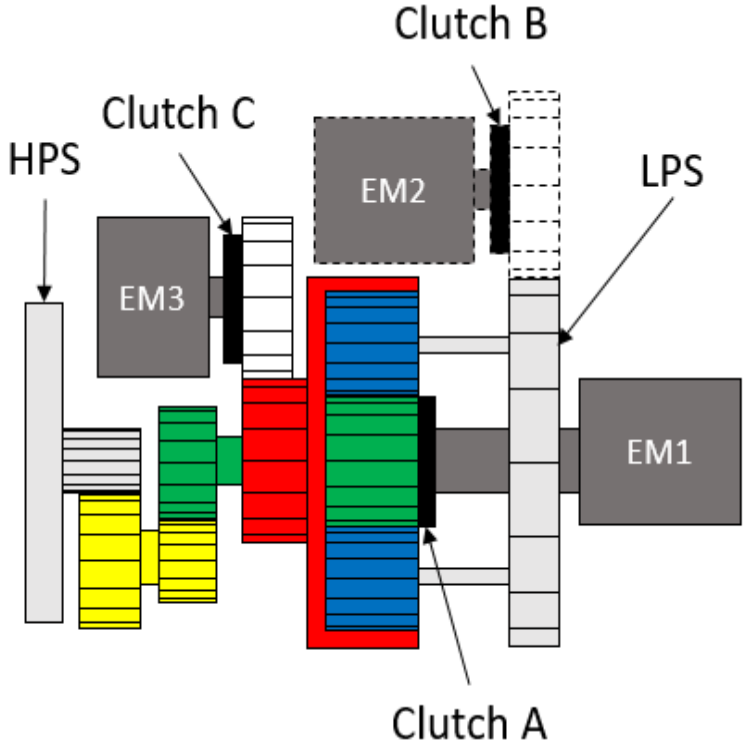
VEATE Gearbox Description

Mechanical planetary gearboxes are not required but are assumed in this study

- Essentially places a planetary gearbox between the HPS and LPS with a free spinning ring gear
- EMs are present to influence each component of the gearbox
  - EM1 influences the sun gear (HPS)
  - EM2 influences the carrier (LPS)
  - EM3 influences the ring gear
- Clutches exist primarily for EM failure isolation



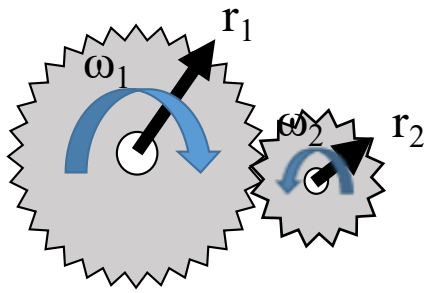
Planetary Gearbox Anatomy



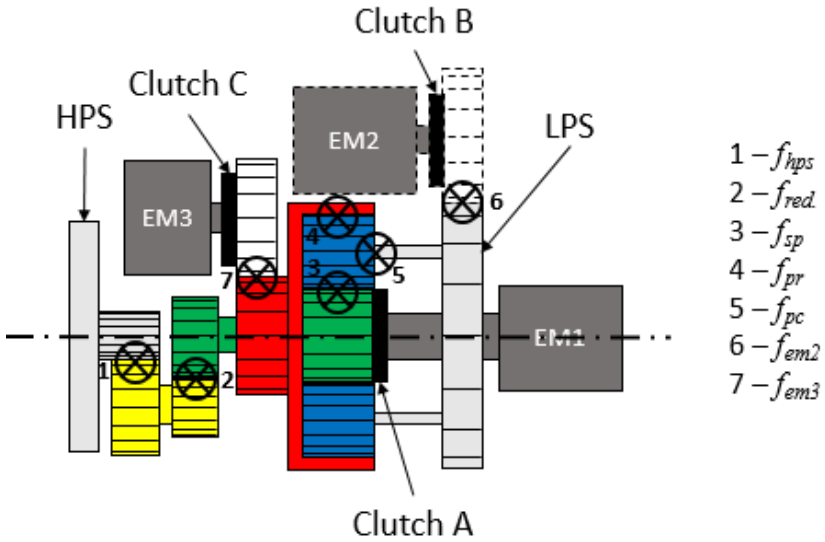
Single Planetary (SP) Variant

VEATE Gearbox Model

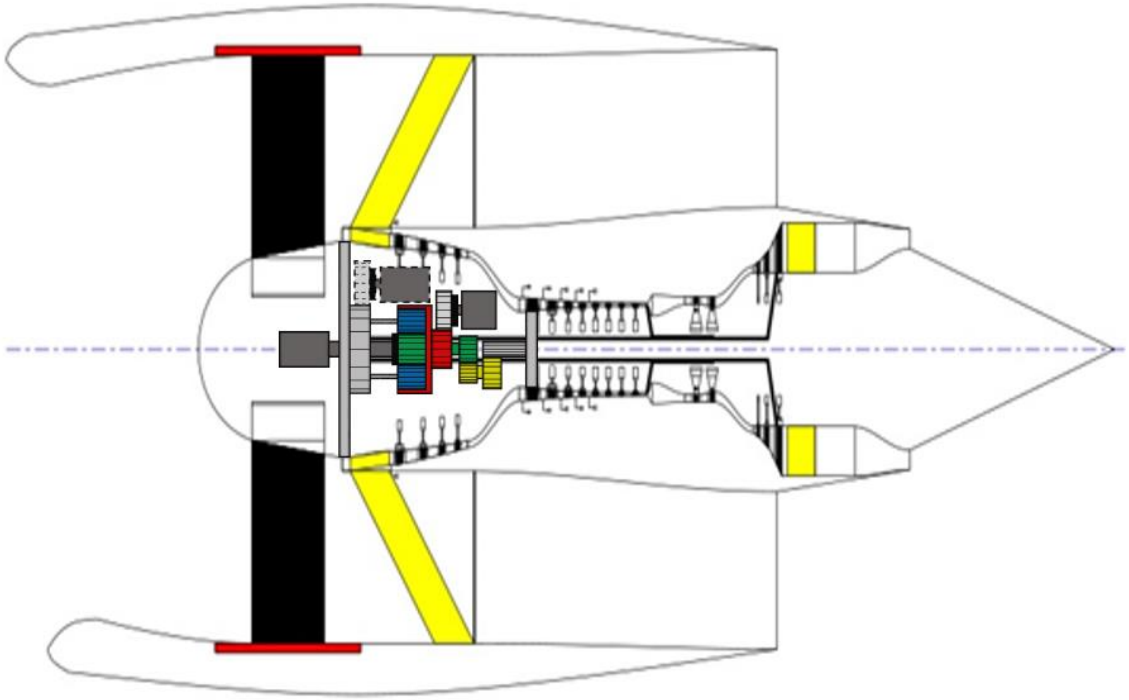
- Enforces physical constraints of the gearbox system
- Captures dynamics of all the gearbox components + the EMs + the engine spools
- Is integrated with the Advanced Geared Turbofan 30,000 lbf (AGTF30) engine model



$$\omega_1 r_1 = \omega_2 r_2$$



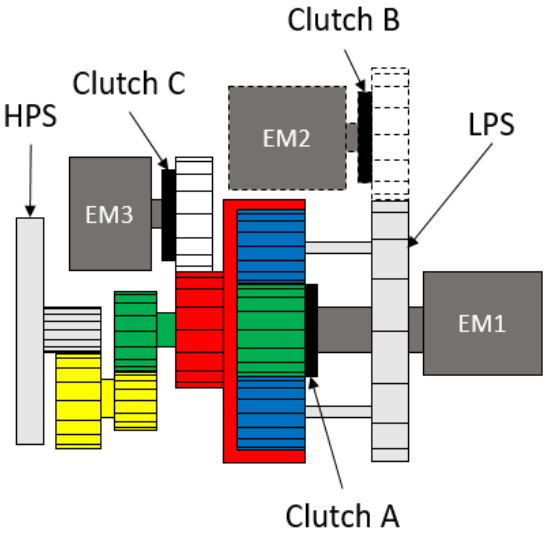
1 – f_{hps}
2 – $f_{red.}$
3 – f_{sp}
4 – f_{pr}
5 – f_{pc}
6 – f_{em2}
7 – f_{em3}



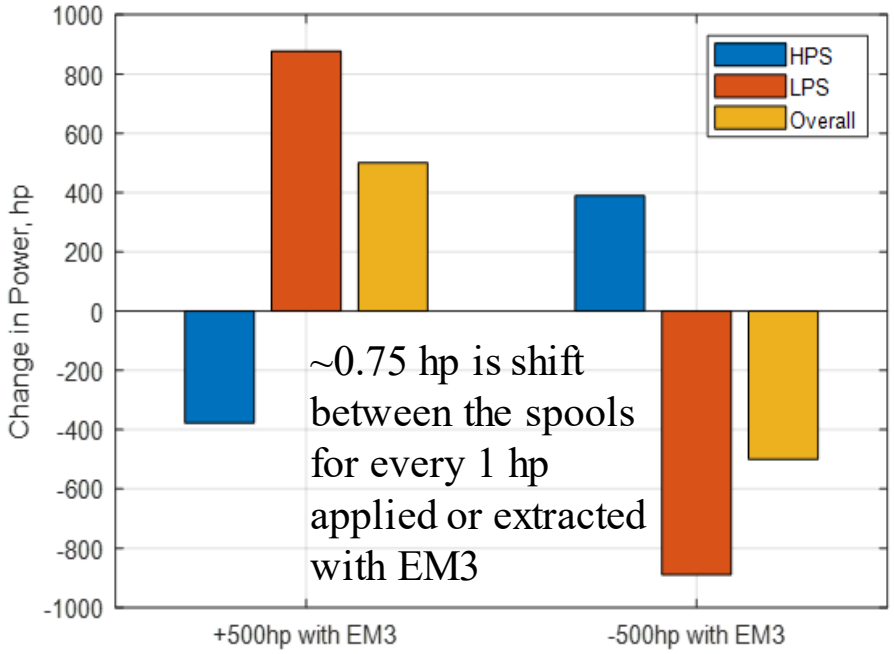
Schematic of the AGTF30 engine with the VEATE gearbox (for illustration only)

Results: Power Effect

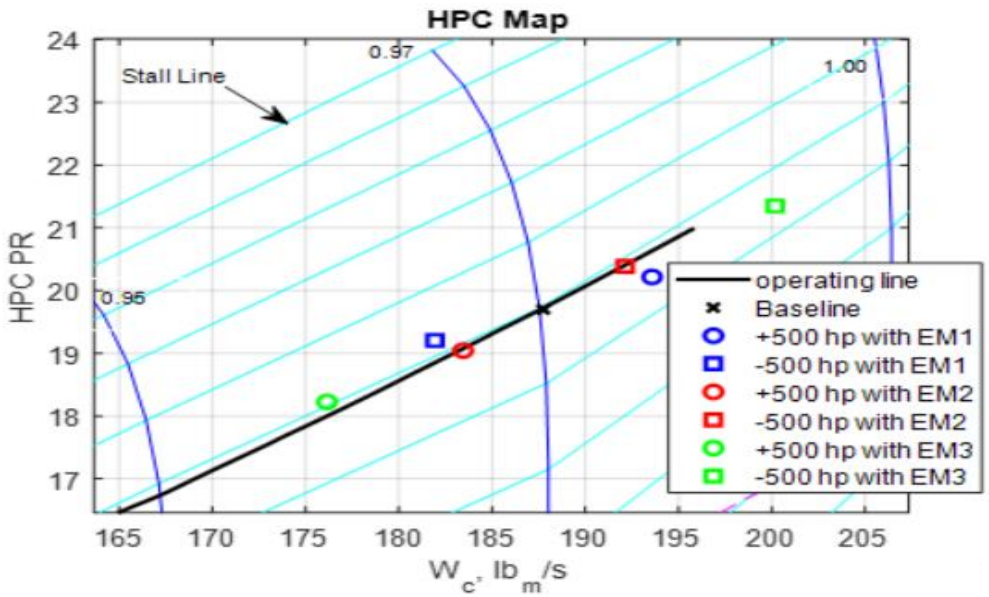
	EM1 (+500 hp)	EM1 (-500 hp)	EM2 (+500 hp)	EM2 (-500 hp)	EM3 (+500 hp)	EM3 (-500 hp)
ΔPower HPS	~ +500 hp	~ -500 hp	~ +0 hp	~ +0 hp	~ -377 hp	~ +389 hp
ΔPower LPS	~ +0 hp	~ +0 hp	~ +500 hp	~ -500 hp	~ +877 hp	~ -889 hp

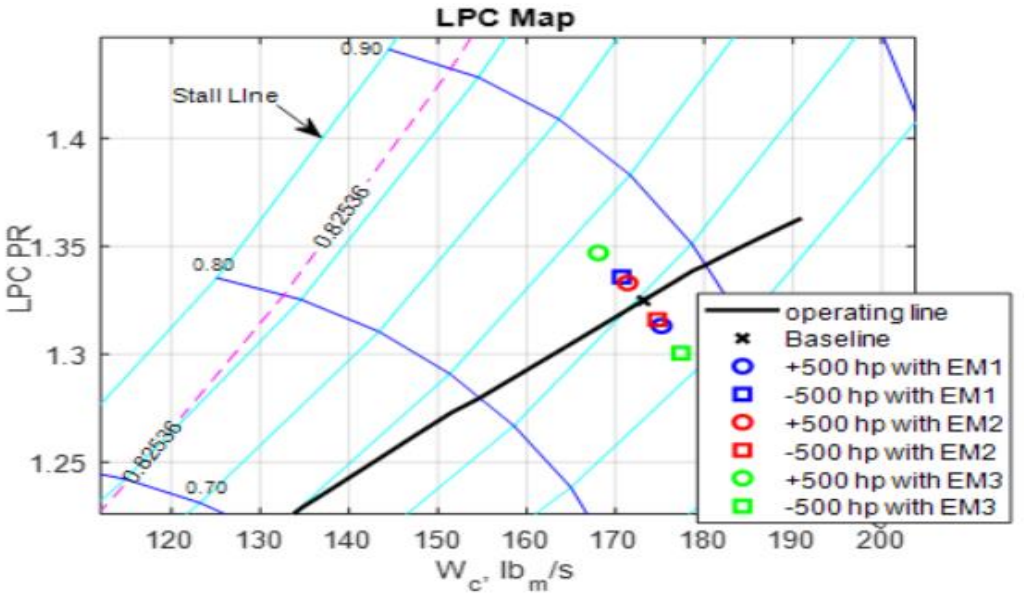


- EM1 essentially only adds/extract power to/from the HPS (equivalent to the HPS EM in the dedicated EM approach)
- EM2 essentially only adds/extract power to/from the LPS (equivalent to the HPS EM in the dedicated EM approach)
- EM3 influences mechanical power transfer between the spools while simultaneously applying or extracting power
- Conclusions:
  - Enables a hybrid method of power management
  - Enables EMs that would be under utilized in a dedicated EM approach to be used to further improve operability (particularly for TEEM)



Results: Power Effect



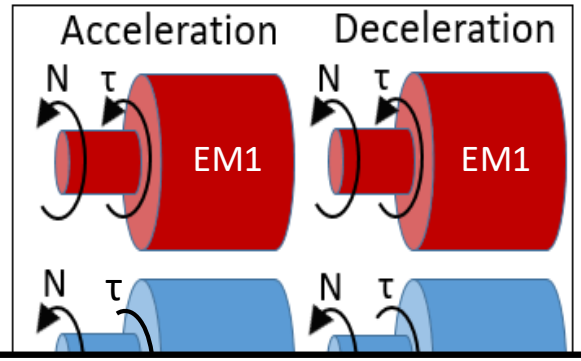


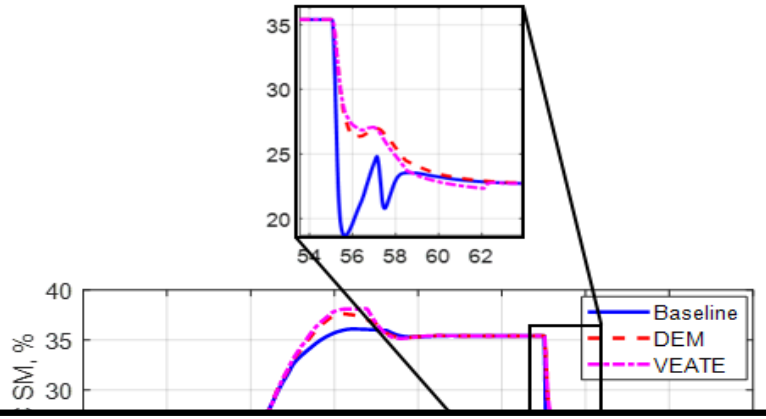
- It's advantageous for HPC operability to …
  - Add power with EM1
  - Extract power with EM3
- Conclusions:
  - EM3 can be used to assist EM1 to improve HPC operability during accels → could reduce the size of EM1 to implement TEEM
  - Power Extraction with EM3 will help to offset the power applied by EM1 → reduces the requirements for the energy storage system

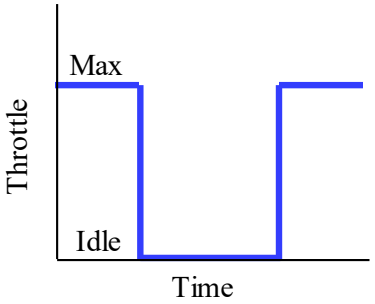
- It's advantageous for LPC operability to …
  - Extract power with EM3
  - Add power with EM1
  - Extract power with EM2
- Conclusions:
  - EM3 is more effective than EM2 at improving LPC operability during transients and can do the same task with less power → reduces overall power system size

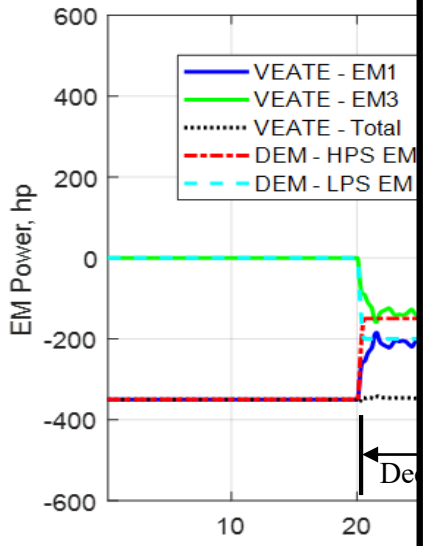
Results: TEEM

- Similar control approach to the DEM option. Difference are:
  - Use of EM3 to supplement EM1 during accelerations
  - Use of EM3 in place of the LPS EM during decelerations
- Chop and burst scenario
- Boosted operability in all cases
- Potential to reduced EM sizes
- Reduced peak power and energy storage u

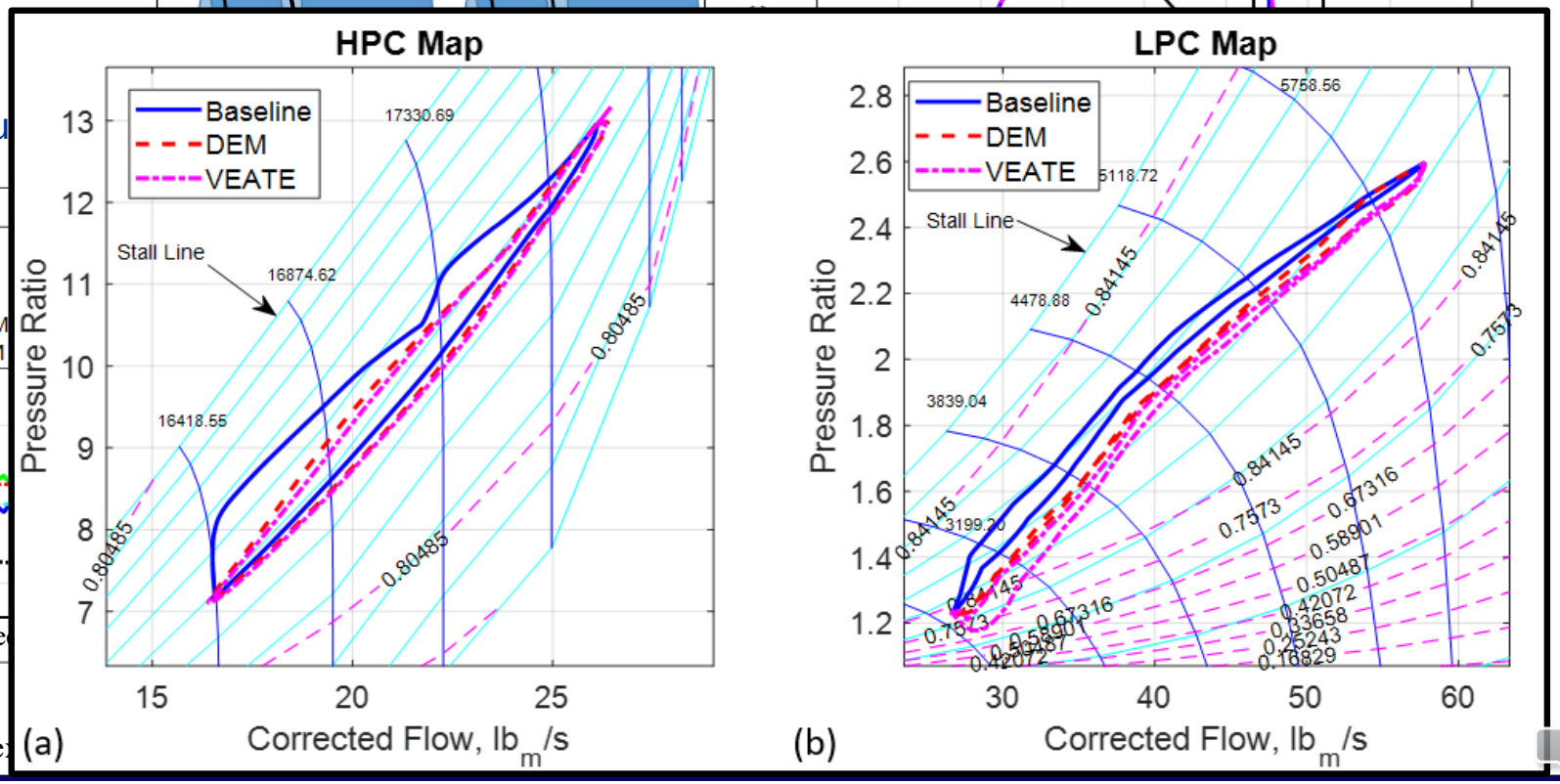






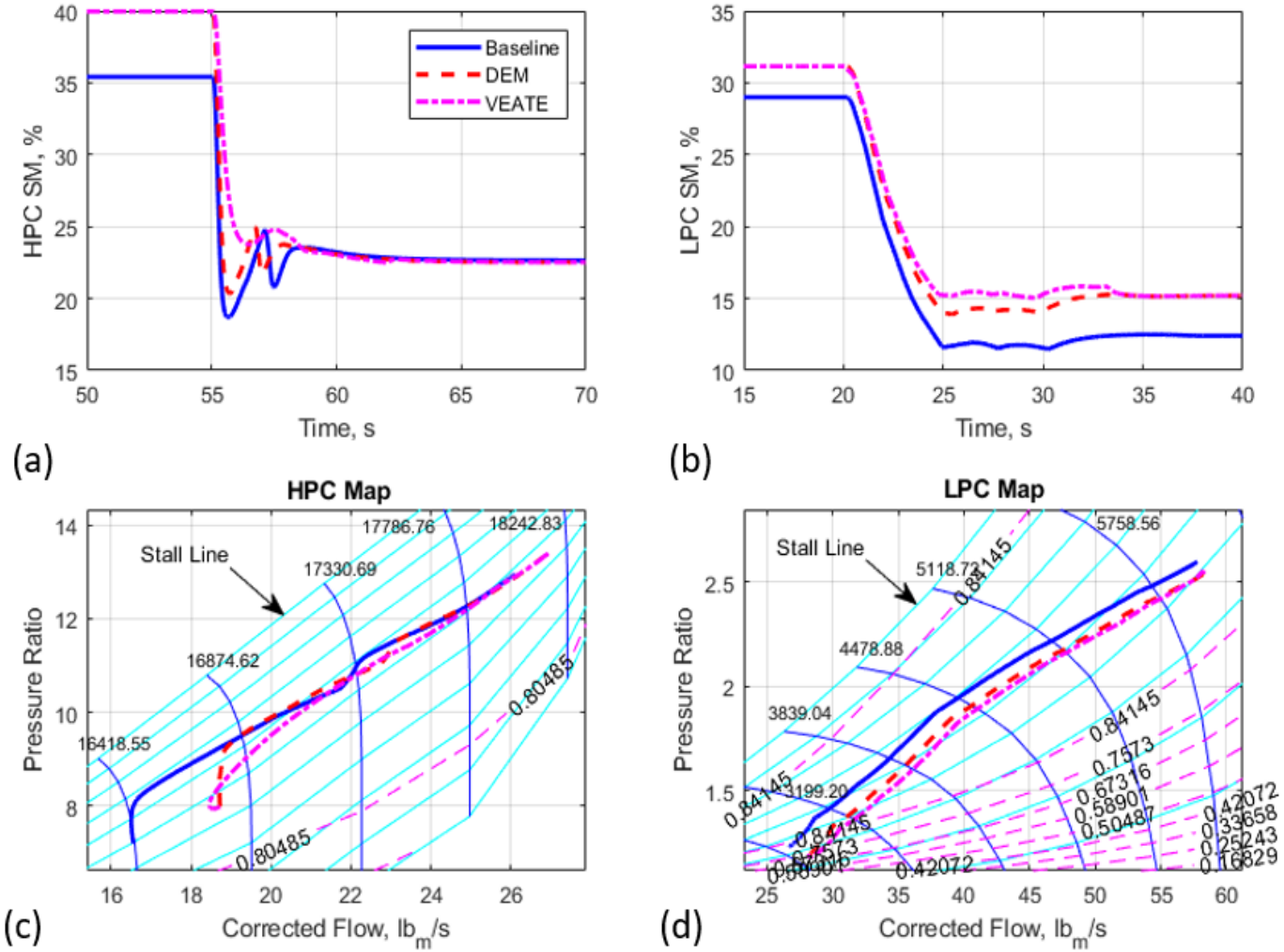


Note: EM1 nominally e



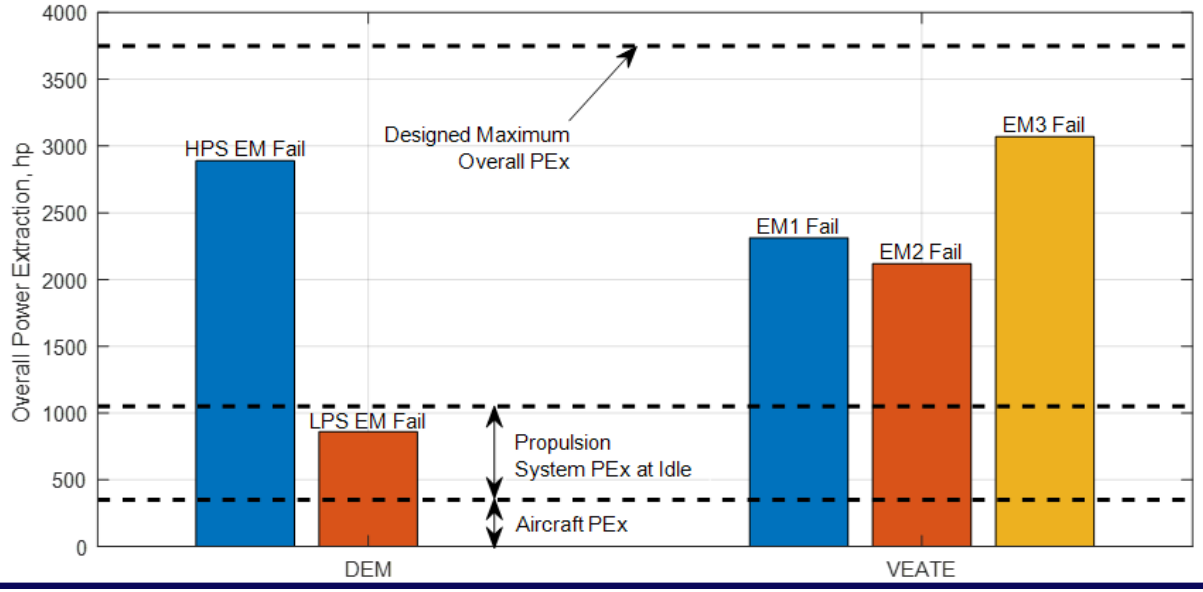
Results: TEEM

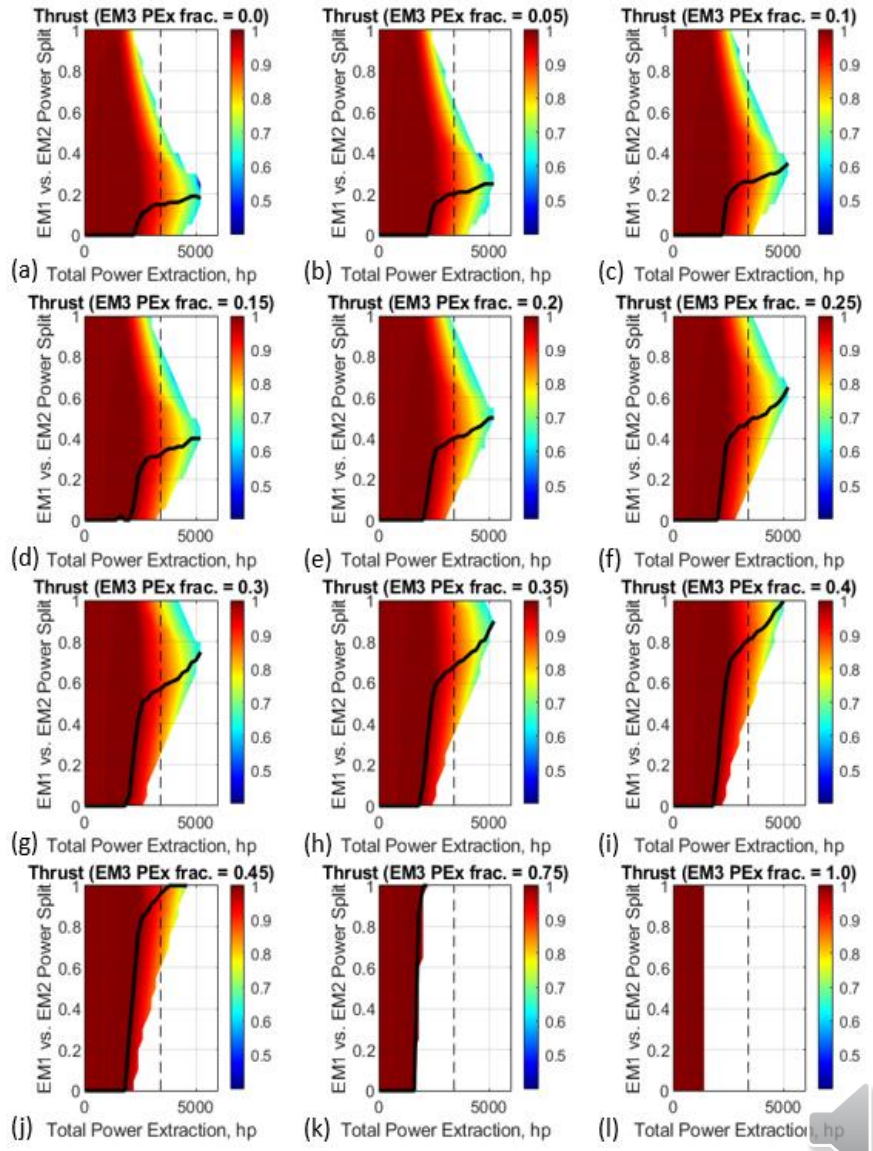
- Considered a failure of the HPS EM/ EM1
  - Importance is related to the need to retain operability with a more aggressive design
- DEM approach:
  - No effective control effort during accels
  - Limited control effort with the LPS EM during decels
- VEATE approach:
  - Uses EM3 during both accels and decels
- The VEATE approach has superior operability with a modest 100 hp EM



Results: Power Extraction

- The VEATE gearbox can shift power between the spools
- Makes more power available on one spool for power extraction
  - Enables flexibility and power splits with similar performance and operability
- More even power splits are possible
  - Optimal split for the DEM approach is ~15%/85% (HPS EM/LPS EM)
  - A split of 32%/48%/20% (EM1/EM2/EM3) is essentially equivalent
  - Worst-case EM failure mode is better for the VEATE configuration





Conclusions

- The paper:
  - provides a description of the Versatile Electrically Augmented Turbine Engine (VEATE) gearbox
  - presents a modeling approach
  - presents a simulation study of the impact of power injection/extraction through the VEATE gearbox
- The VEATE gearbox provides a hybrid method for managing power on the spools of a gas turbine engine
- There is evidence to suggest that the VEATE gearbox could:
  - reduce the electrical power system size (particularly for Turbine Electrified Energy Management (TEEM))
  - introduce flexibility to power injection/extraction implementation
  - improve system robustness and safety through inherent fail-safe features

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Contact Information

jonathan.kratz@nasa.gov

dennis.e.culley@nasa.gov