Emission Characteristics of an Axially Staged Sector Combustor for a Small Core High OPR Subsonic Aircraft Engine

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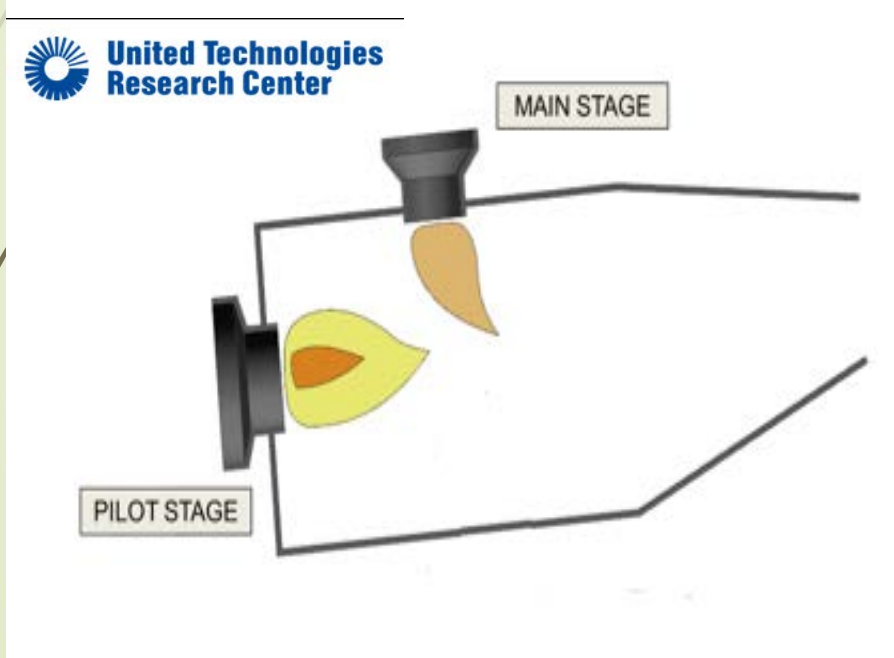
NASA Advanced Air Transport Technology (AATT)

- Small core, high OPR (50+), engine
- gas-only and hybrid gas-electric aircraft
- Engine combustor, reduce Nitrogen Oxides (NOx) emissions to 80% below ICAO CAEP/6 standard (TRL 3)
- fuel-flexible combustors
- Cruise NOx reduced 80% below 2005 best-in-class

Contract or Space Act agreement

United Technologies Research Center

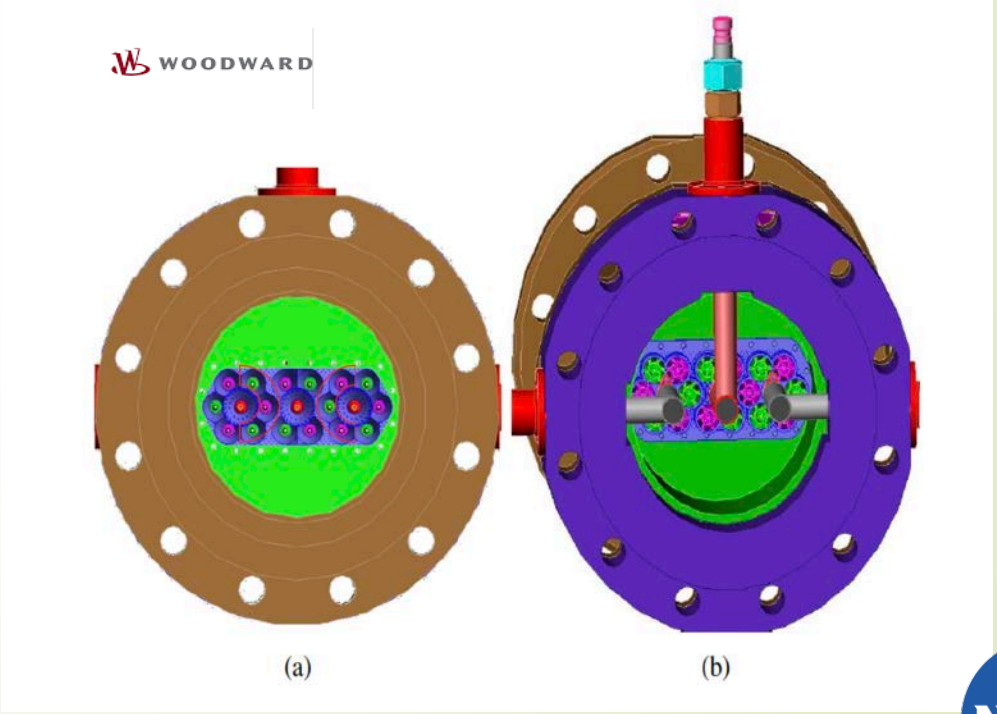
Axially Controlled Stoichiometry (ACS) combustor



Report here

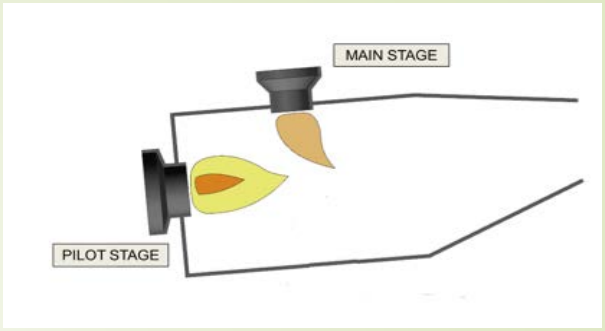
Woodward, INC

3-cups Lean Direct injection (LDI) combustor



Reported, > 80% NOx reduction

UTRC ACS combustor



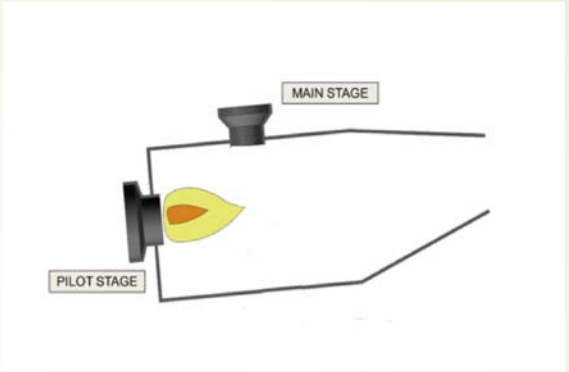
- ACS combustor concept used previously in NASA ERA project by P&W
- Single-cup combustor
  - one of 14 sector for core-size 2.0
  - rated 15,000 lbf thrust at sea-level take off.
- Two single-cup combustors were built under this contract.
  - One with water cooled combustor liners for UTRC HPHT rig
    - full engine power conditions
    - Screen injectors and other combustor feature.
  - One with air cooled combustor liners. NASA Glenn CE-5 rig.
    - Best configuration
    - More close to real engine combustor designs
    - Verify NOx emissions reductions
- NOx, CO and Particulate Matters (PM) emissions data of NASA CE-5 ACS combustor are reported

Test facilities

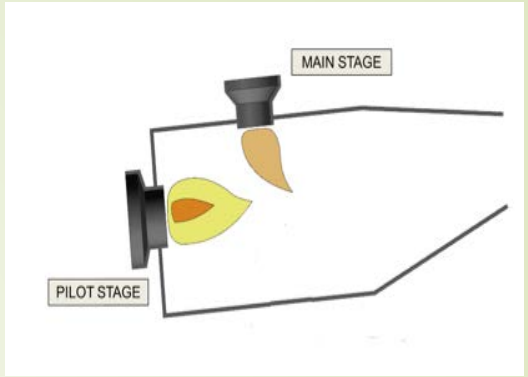
- NASA Glenn Research Center's CE-5 combustion rig
- Inlet air: up to 922 k and 19 bar
- fuel: Jet-A, and 50/50% GEVO/Jet-A alternative fuel (alt fuel data not report here)
- Traversing gas probe at combustor exit
- fixed particle probe 20 cm behind

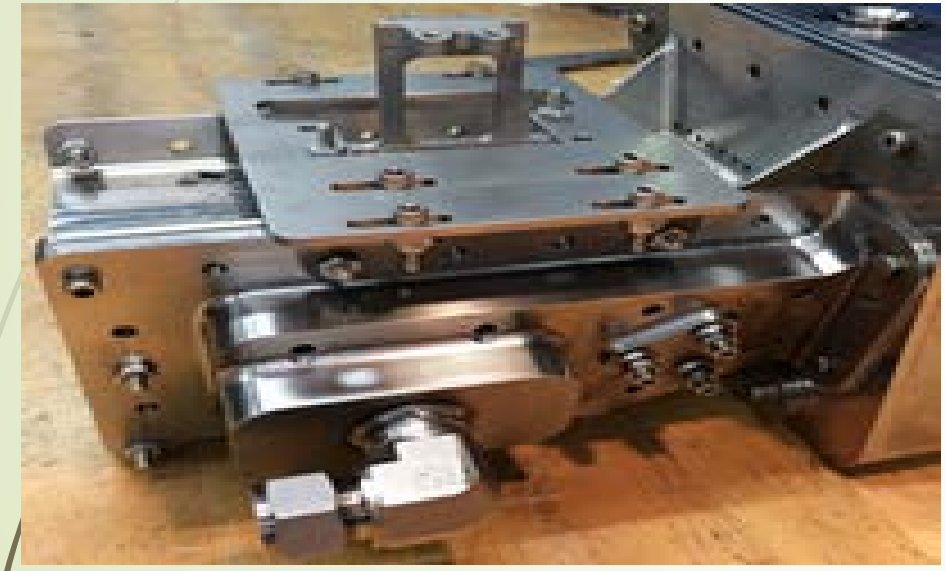
Test hardware

Low-power

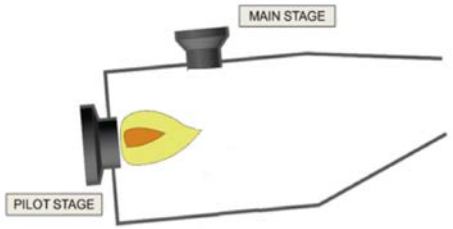


High-power

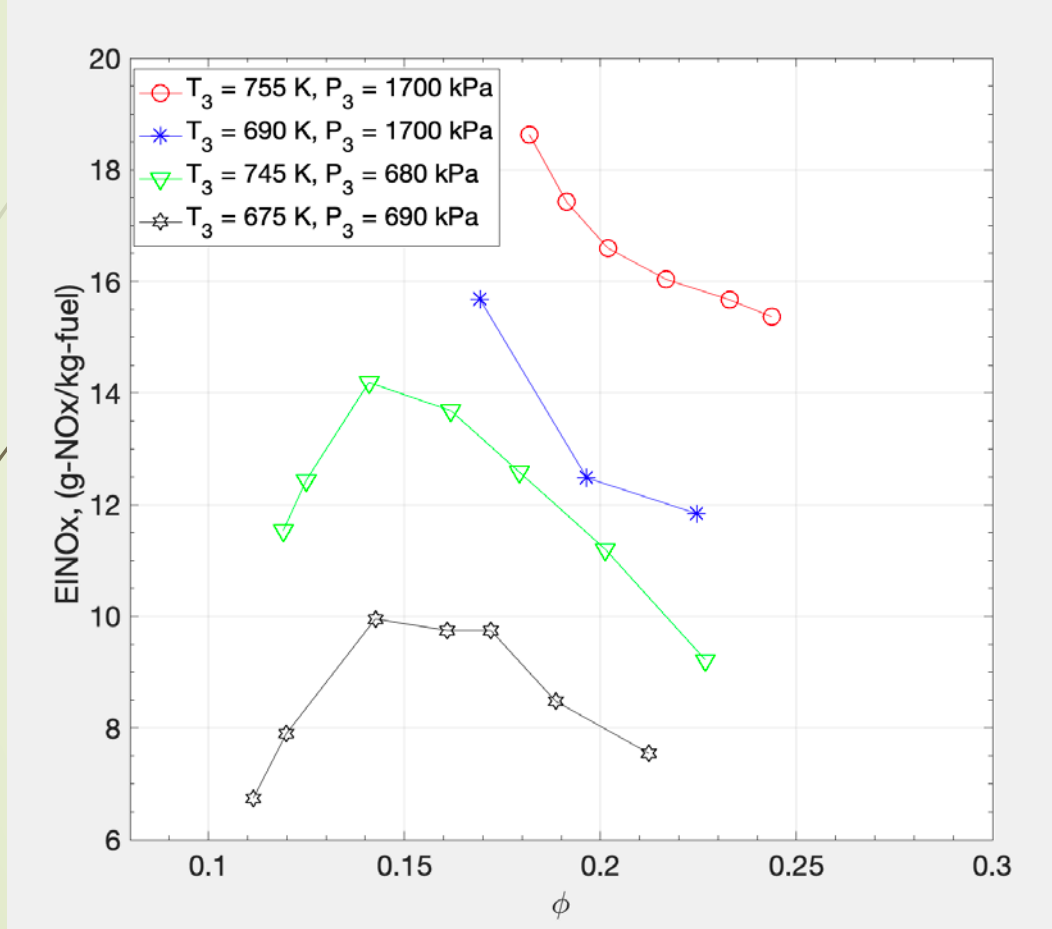


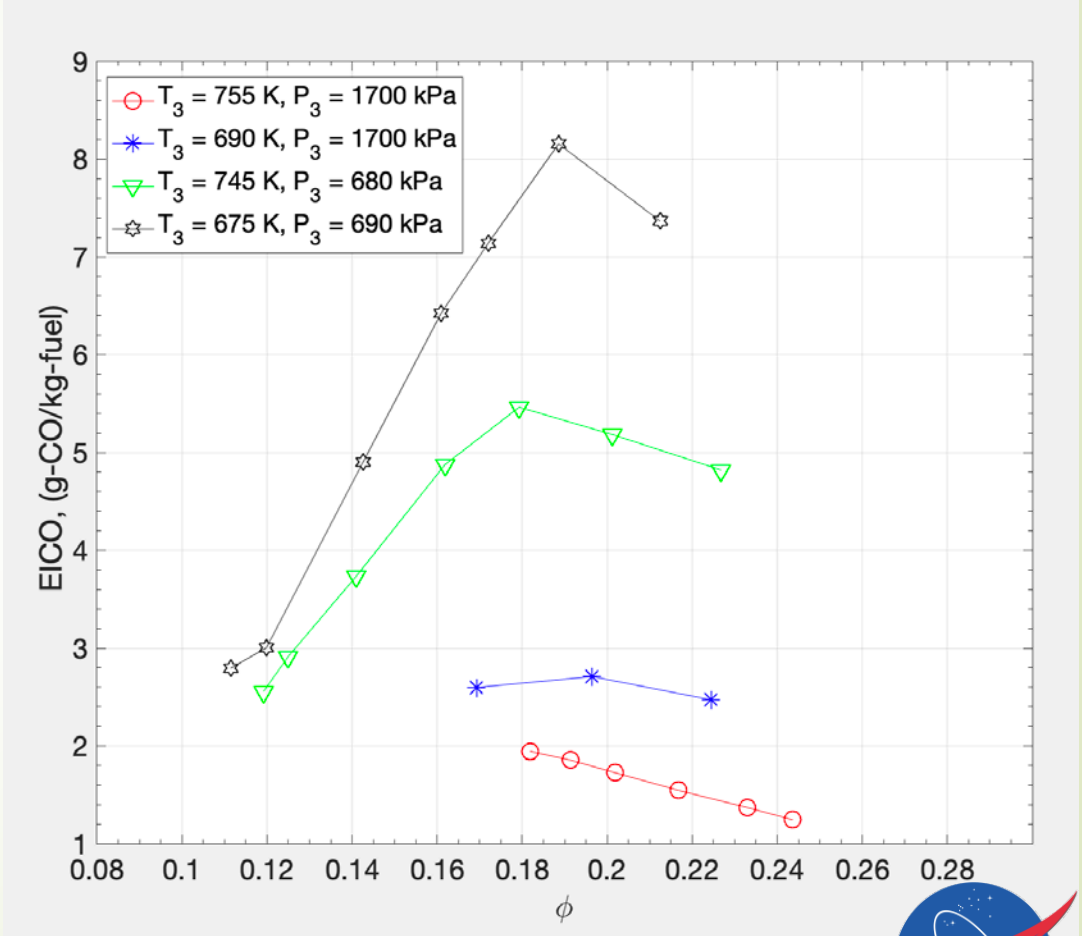


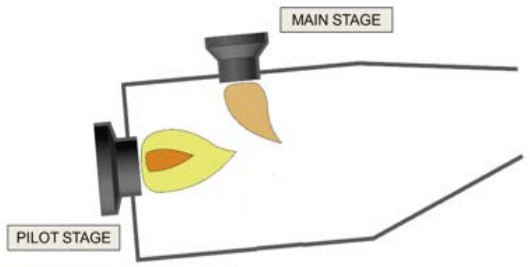
- Pilot injectors located front dome
- Main injectors on top liner downstream
- Combustion air cool liners top and bottom
- Left and right is metal plates
  - cooled by a separated source air
- Three fuel circuits
  - Two for pilot injectors.
  - One for main injectors.
- Two operational configurations
  - Low-power configuration (Pilot only)
  - High-power configuration (Pilot and Main)



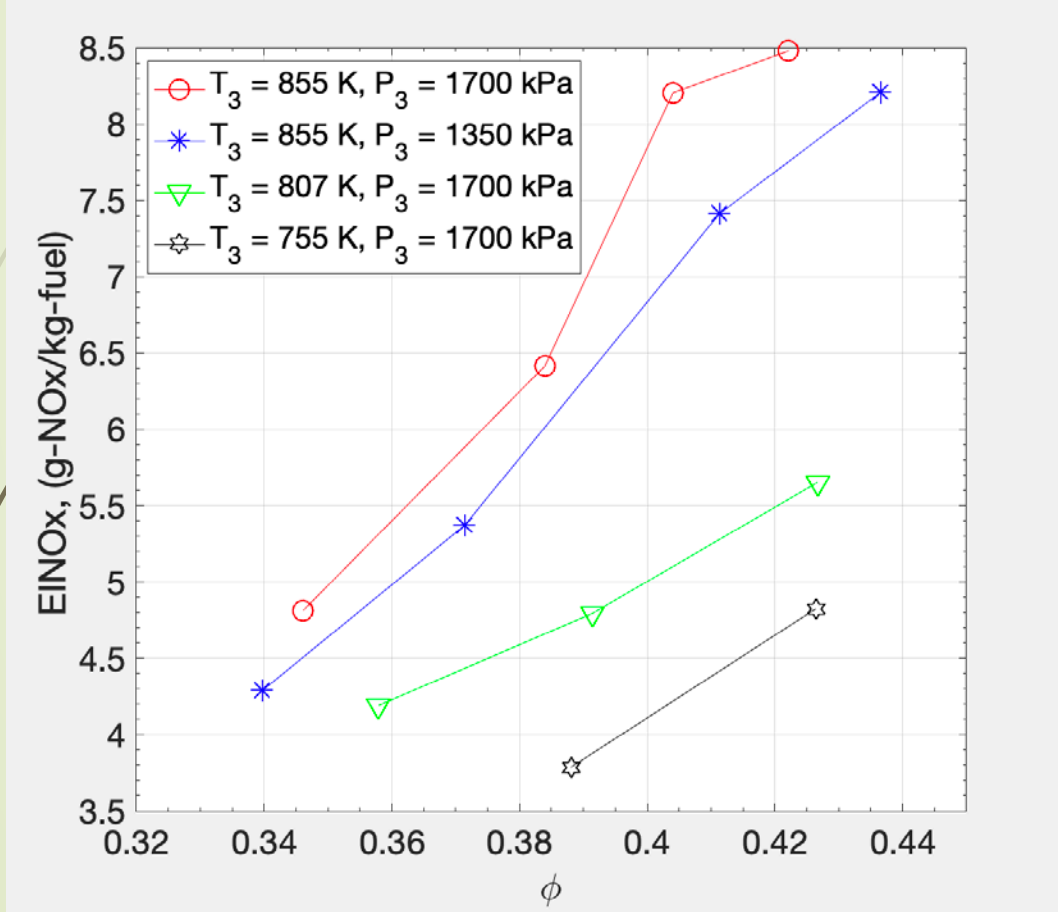
Results- NOx and CO emissions at Low-power configuration (pilot only)

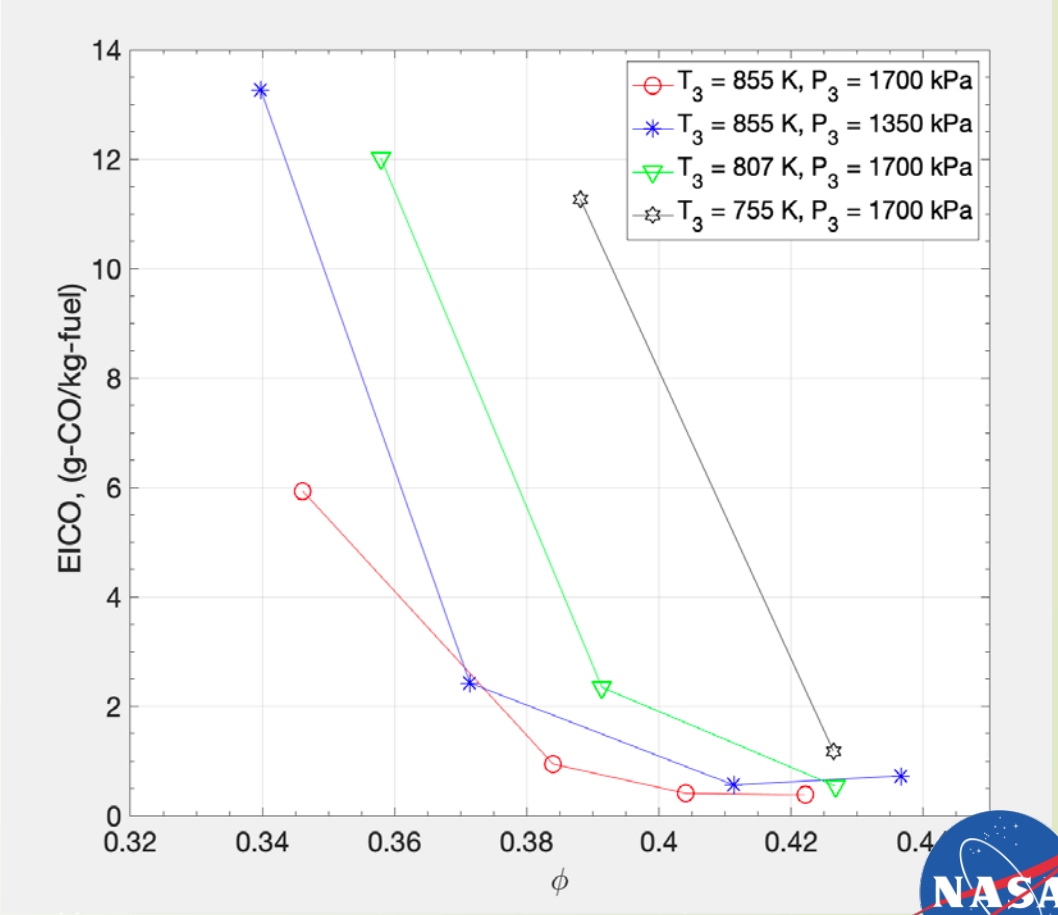




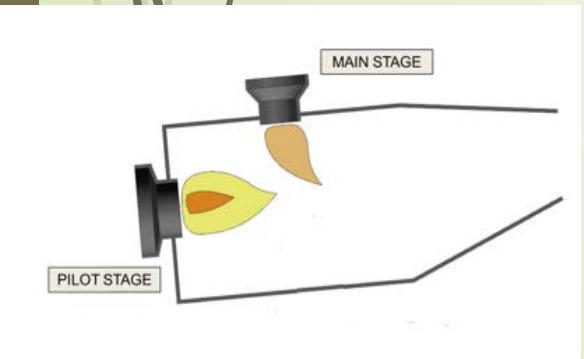


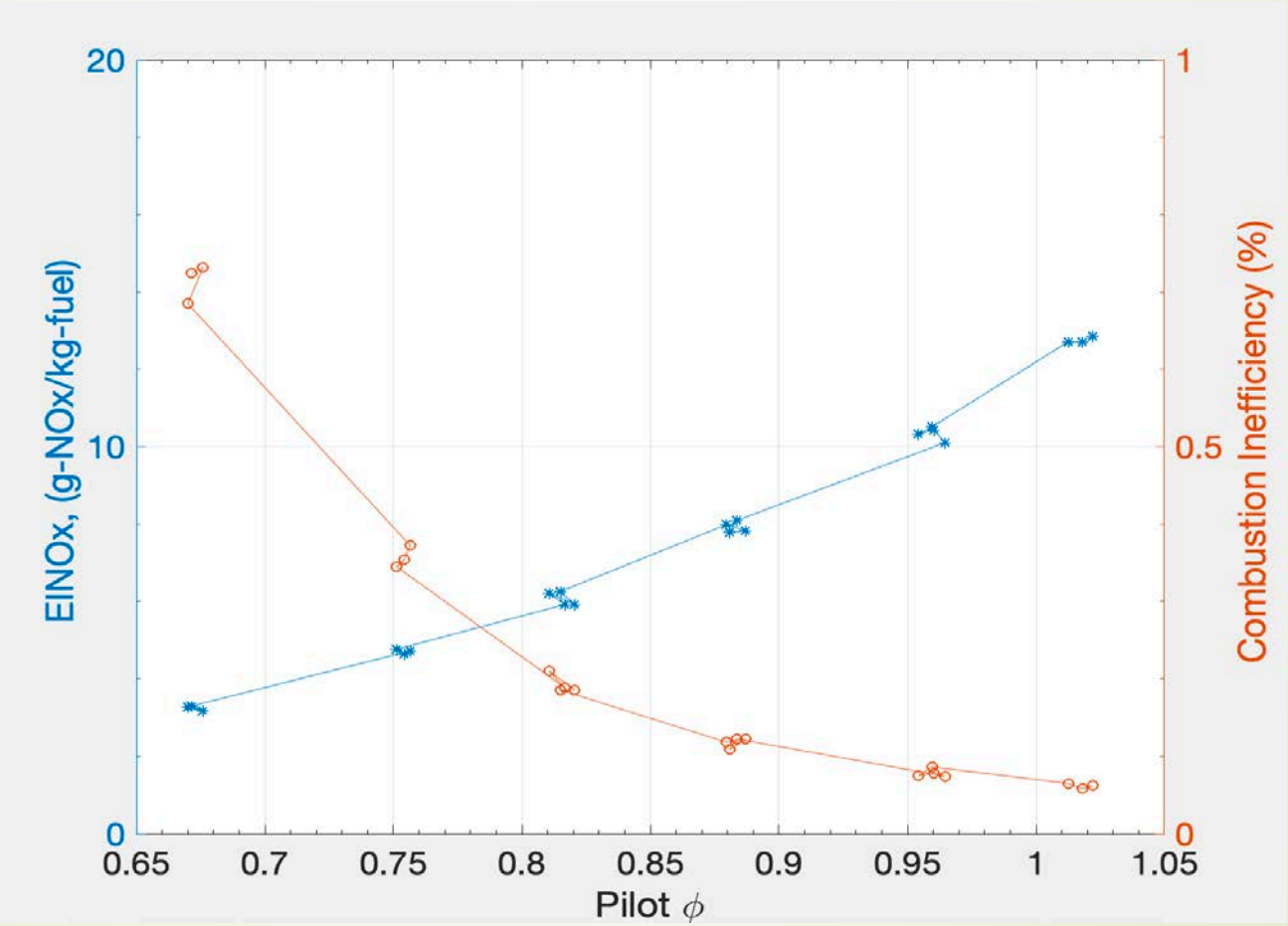
Results, NOx and CO emissions at High-power configuration (pilot and main)

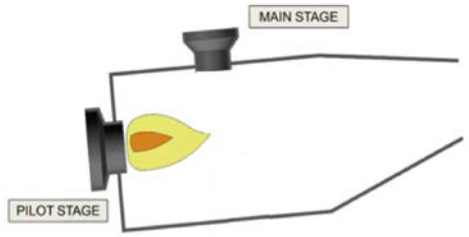




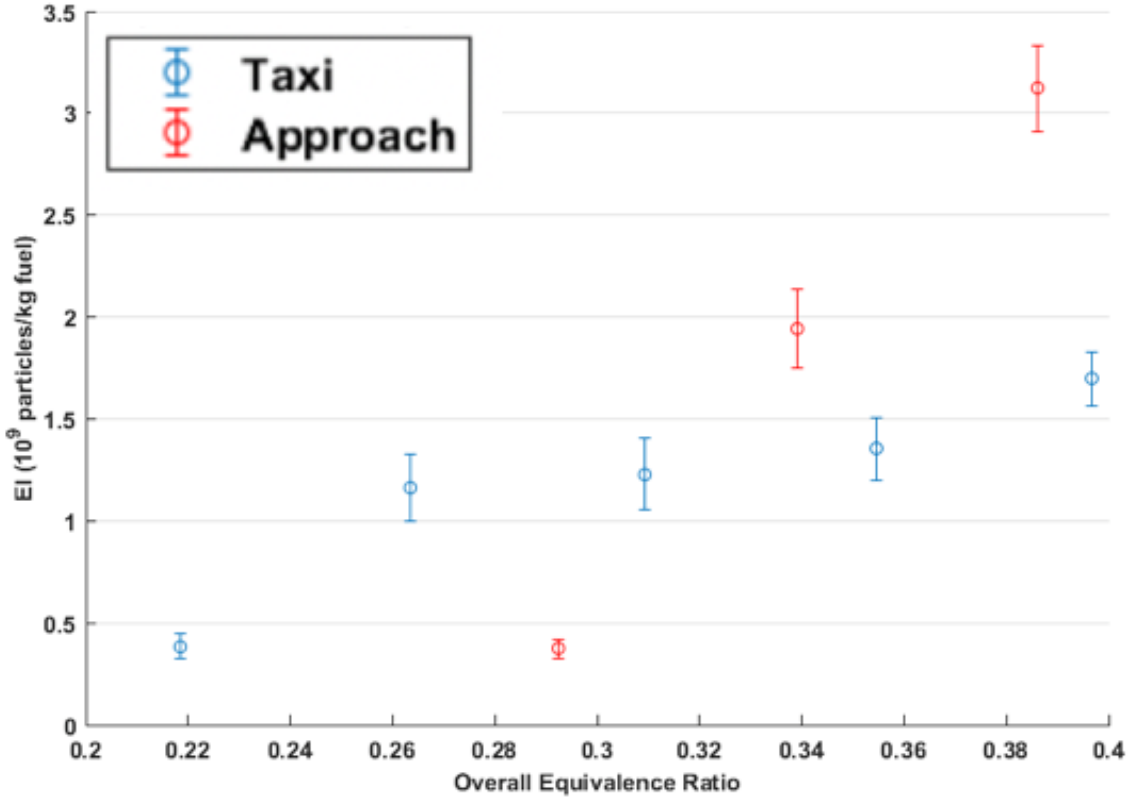
Fuel split between pilot and main injectors

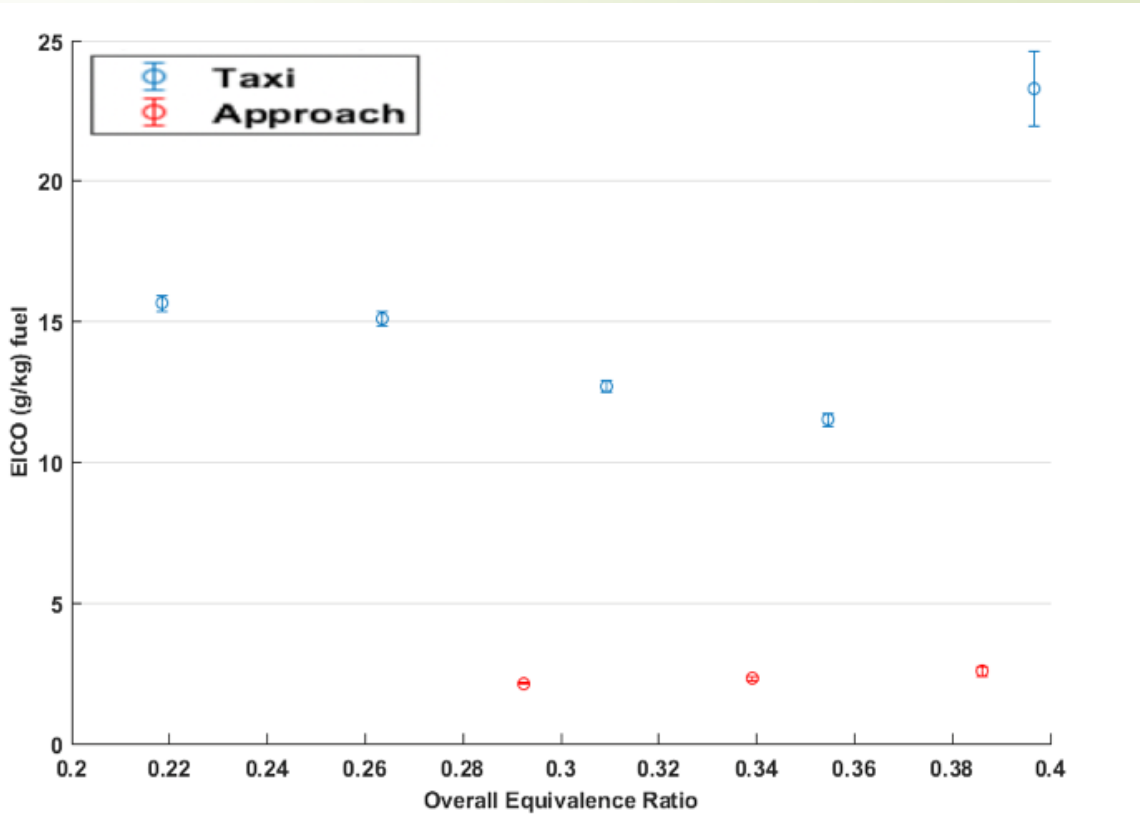


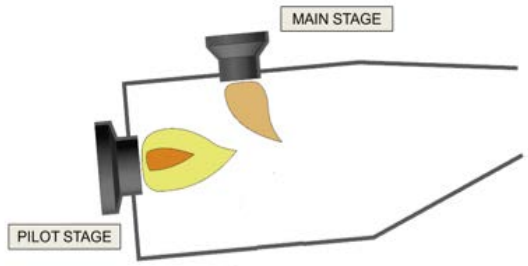




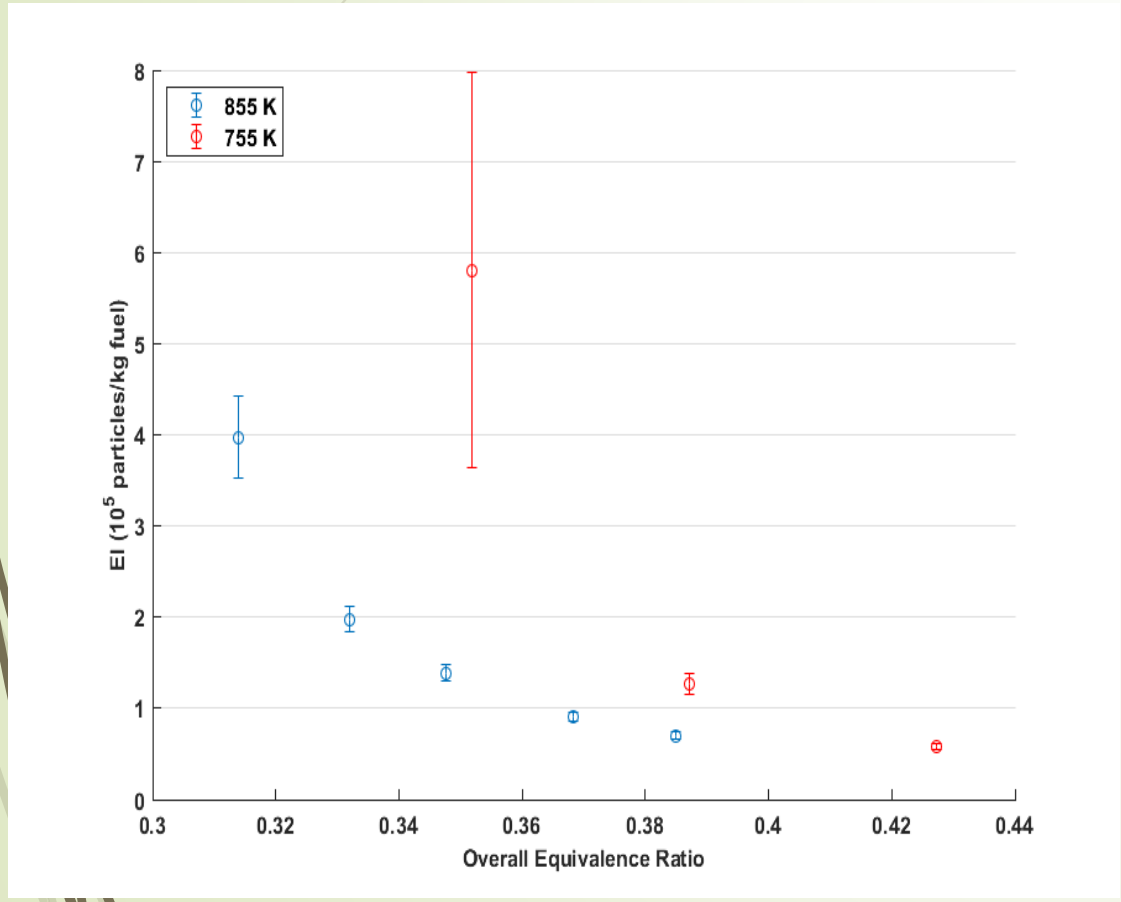
Particulate Matter (PM) and CO emissions —Low-power configuration

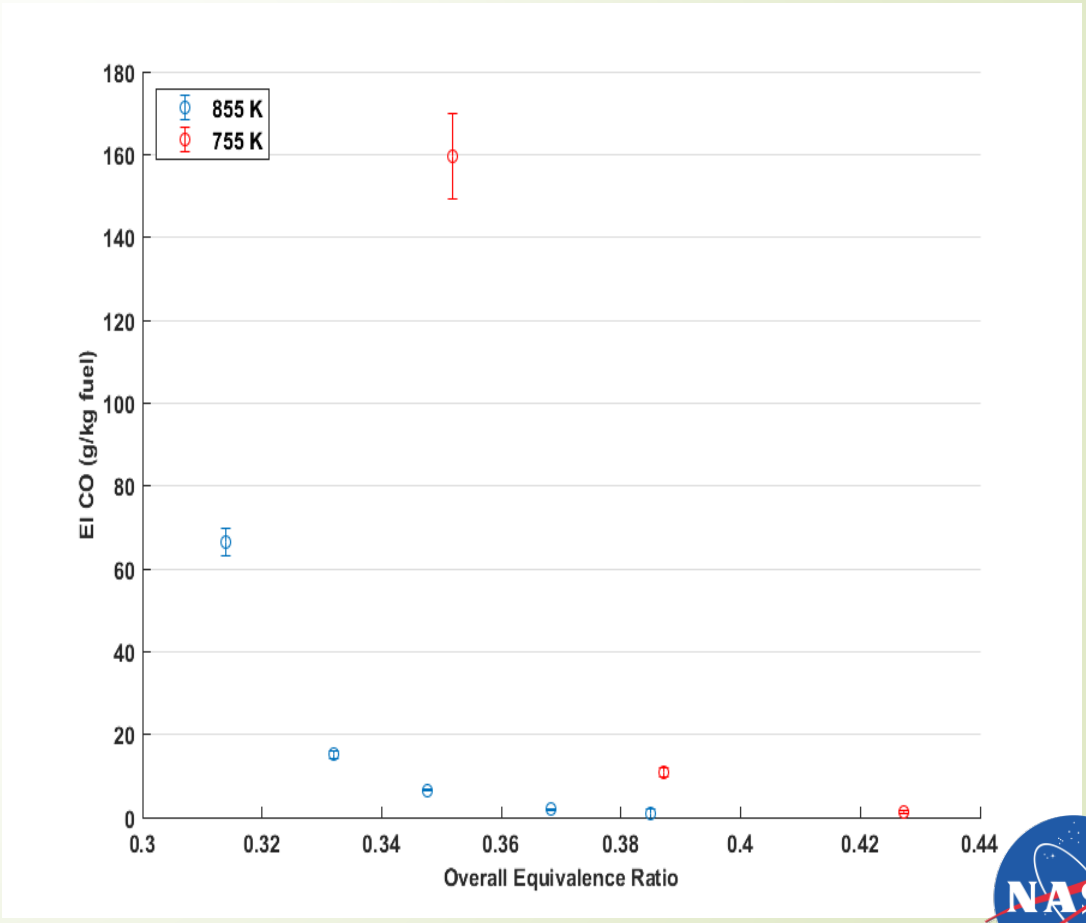






Particulate Matter (PM) and CO emissions —High-power configuration





EINOx correlation equations

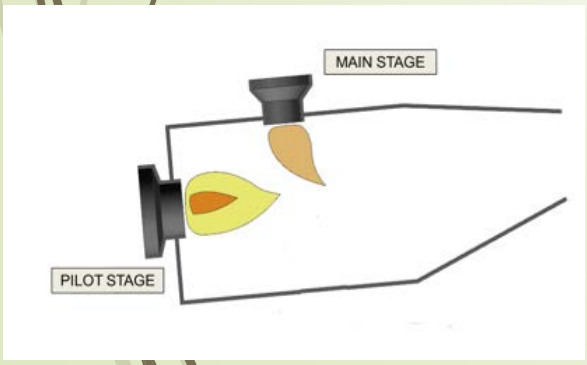
Operational conditions	NO_x correlation equations
Low-power configuration $0.07<\emptyset<0.15$	$EINOx = 0.141 \times (-19.14 - \frac{4.411}{\emptyset} + \frac{0.07856}{\emptyset^2} + \frac{17.56}{\sqrt{\emptyset}}) \times P3^{0.515} \times e^{\frac{T3}{298}}$
Low-power configuration $0.35>\emptyset>0.15$	$EINOx = 0.016 \times (21.7 + \frac{4.39}{\emptyset} + \frac{0.064}{\emptyset^2} - \frac{17.44}{\sqrt{\emptyset}}) \times P3^{0.327} \times e^{\frac{T3}{287}}$
High-power configuration $\emptyset>0.30$	$EINOx = 2.56e^{-3} \times P3^{0.48} \times \emptyset_{pilot}{}^{2.72} \times \emptyset^{0.11} \times e^{\frac{T3}{168}}$

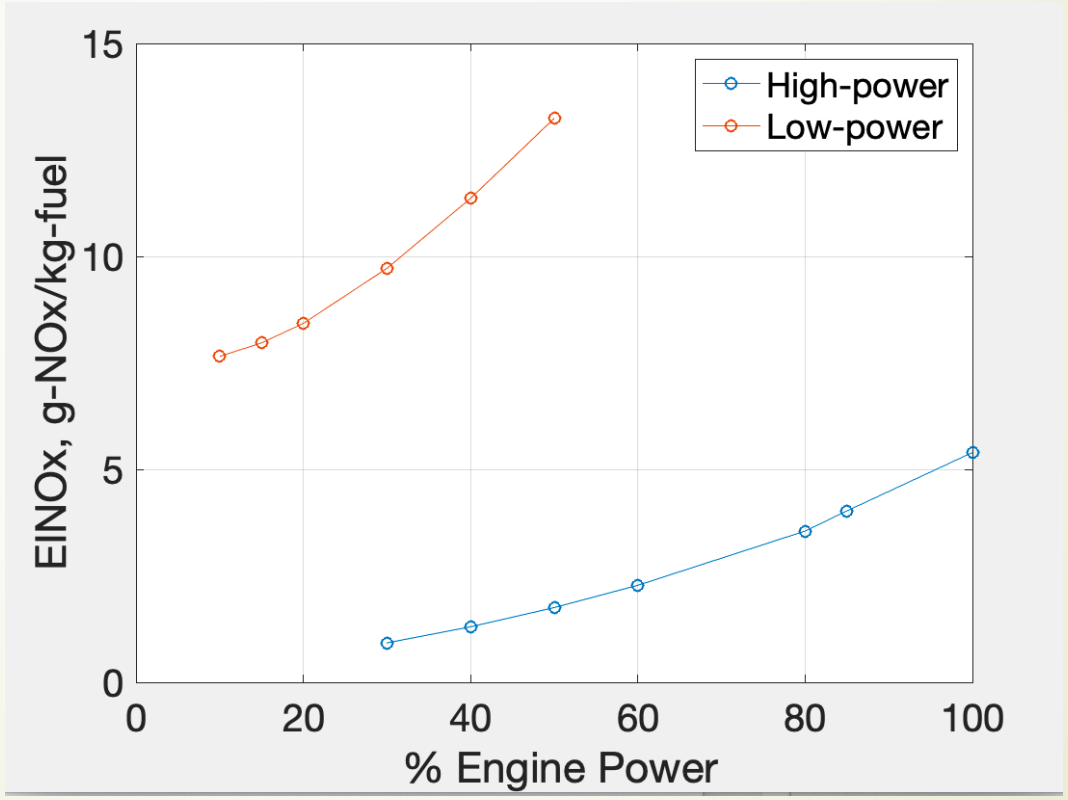
- P3 in kPa, T3 in K

NASA N+3 engine LTO cycle for 120.4 kN, 37.6 OPR (sea-level) engine.

% engine power	LTO condition	P3 (bar)	T3 (K)	ø	Fuel (kg/s)
100	SLTO	38.0	870	0.354	0.585
85	Climb	32.7	835	0.325	0.479
30	Approach	14.1	661	0.185	0.147
7	Taxi	7.1	553	0.102	0.048

NOx emissions estimation over NASA's N+3 engine power setting.





ICAO NOx reduction in relative to CAEP-6

% engine power	conditions	NASA N+3 cycle $EINO_x$	UTRC N+3 cycle $EINO_x$ *
100	SLTO	4.65	4.02
85	Climb	3.48	3.09
30	Approach	10.2	10.7
7	taxi	3.46	6.12
	cruise	2.56	1.6
		% ICAO reduction	**% ICAO reduction**
		89%	82%

* Calculated from correlations developed from NASA test data.
* The NO_x emissions results are humidity corrected

Conclusions

- NOx, CO, PM emissions of a small core high OPR ACS combustor are reported
- NOx and CO emissions characteristics are similar to a previous version of ACS combustor
- PM emissions data is not compared to most other PM data collected at the exit of the engine
- Low-power configuration (rich front end) is producing significant higher PM emissions that High-power configuration (lean front end)mode.
- 82% and 89% NOx reductions in relative to ICAO CAEP/6
- Over 80% reduction in Cruise NOx relative to a NASA-defined 2005 best-in-class

Acknowledgments

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Questions and Comments