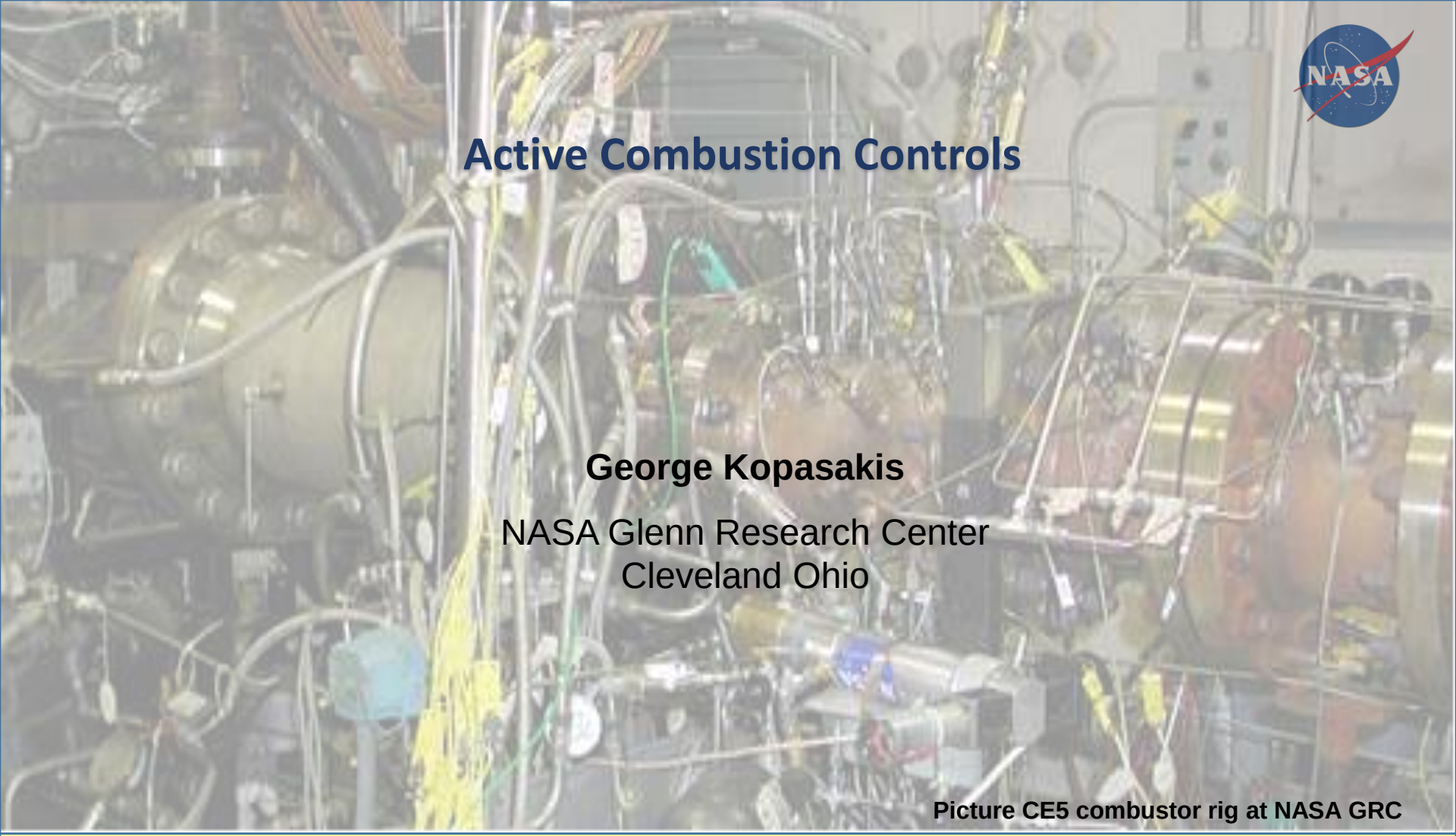


# Active Combustion Controls

**George Kopasakis**

NASA Glenn Research Center
Cleveland Ohio

Picture CE5 combustor rig at NASA GRC

**NASA – Pratt/UTRC Meeting**
**Nov. 15, 2017**

# Outline

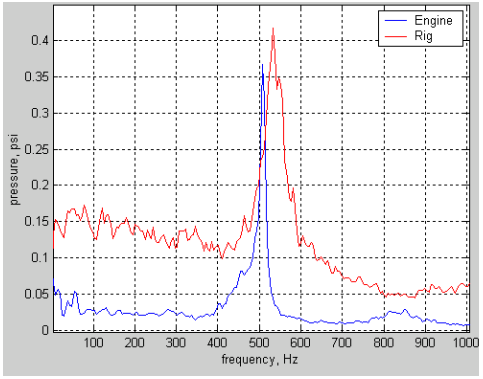
- ACC Background & Questions where we go from here
- Pattern Factor Background - Questions
- Emissions Minimizing Controls Background - Questions
- Conclusions

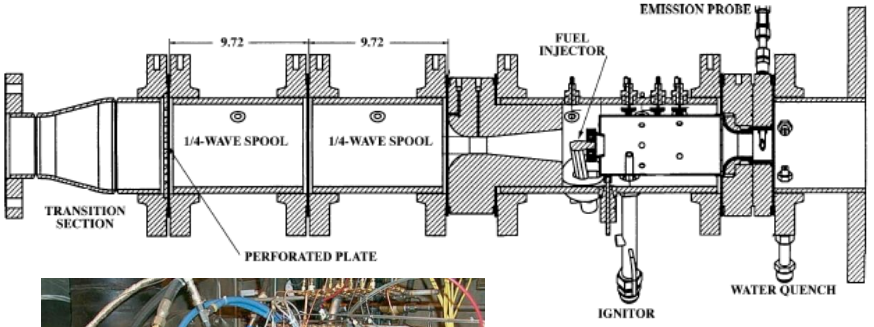
# Background & History

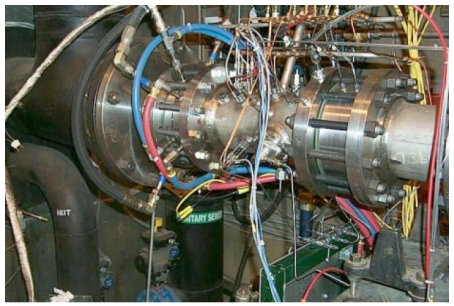
**Lean burning combustors are advantageous for emissions reduction however, they are susceptible to thermos-acoustic instabilities**

- Problem recognized since the early 70's, but series efforts to understand and address this problem started in late 80's
  - -- Both passive and active (feedback control) techniques have and are being investigated.
  - -- NASA started an effort in late 90s – early 2000's to address (a) *instability control*, b) *burner pattern factor control*, and c) *emissions minimizing con*trol.
  - -- Up to that point some instability investigations/ACC were done in pulse tube or atmospheric type combustors, but never before in a realistic engine environment. So NASA partnered w/ Pratt/UTRC to develop a realistic engine like combustor to help understand the problem (modeling) and to attempt ACC.

Rig at UTRC Developed to duplicate Instability observed during development of high-performance aircraft gas-turbine engine



# ACC Results from the NASA Effort

## Virginia Tech in 2000

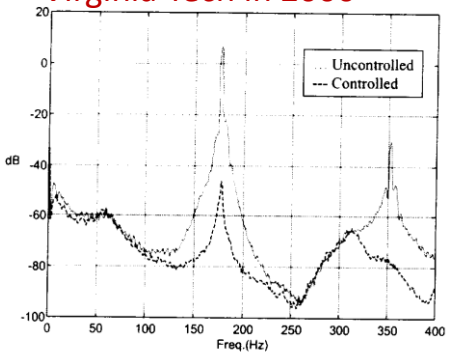
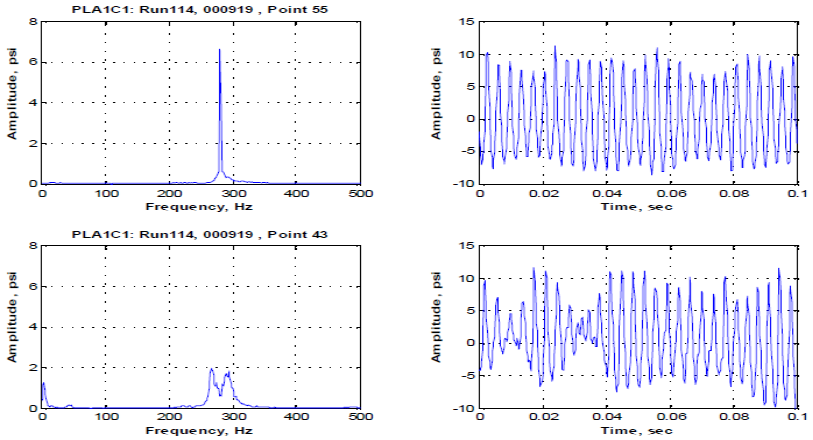
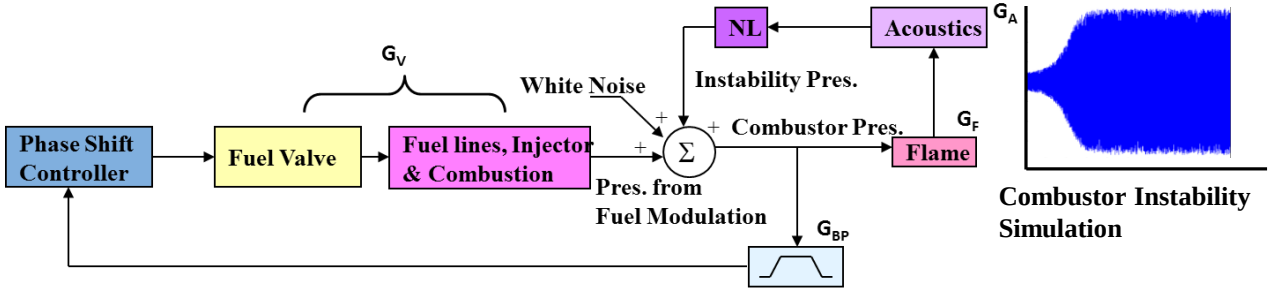



**Figure 13 - Experimental data for a Rijke tube combustor operating at an equivalence ratio of about 0.51 and a total flow rate of 120 cc/sec.**

## Pratt/UTRC in 2000



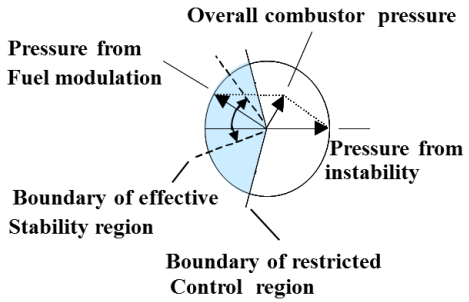

- Two different control methods were developed at GRC in 2001, with somewhat comparable results. Only one of them is briefly covered here.



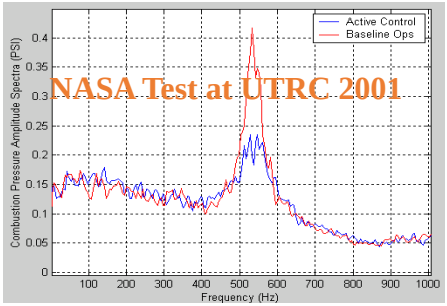

**Combustor Instability Controls Diagram**



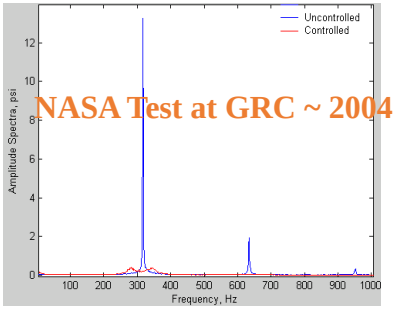
**Combustor Instability Simulation**



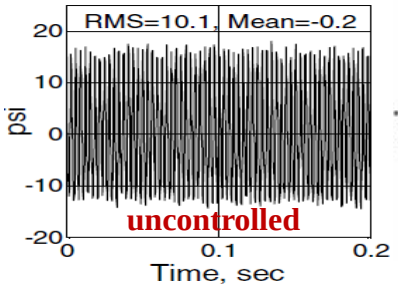

**Adaptive Sliding Phasor Average Control Method - Control of relative phase angle of fuel nodulation and instability**

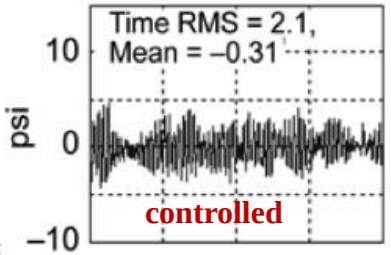



**NASA Test at UTRC 2001**



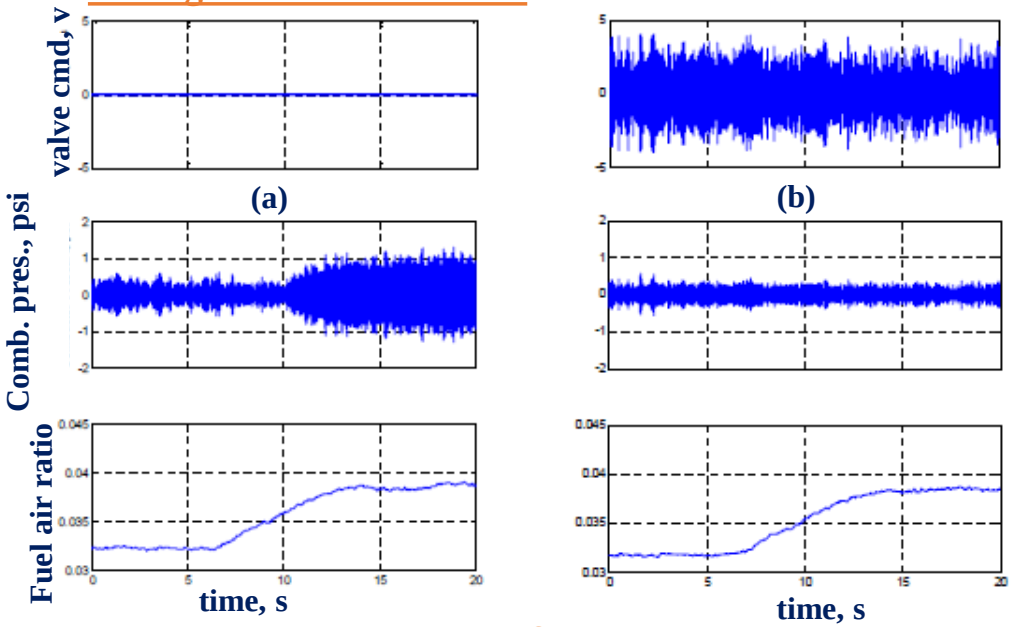

**NASA Test at GRC ~ 2004**



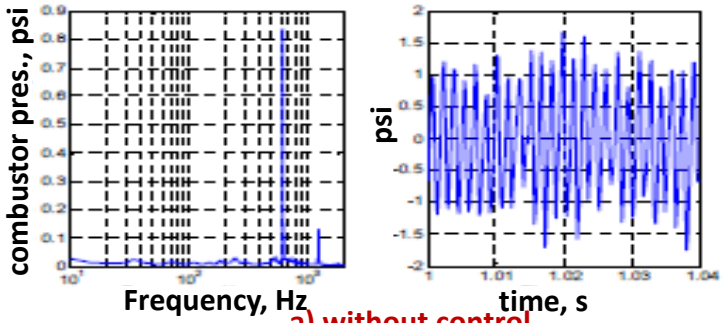



# ACC Results from the NASA Effort

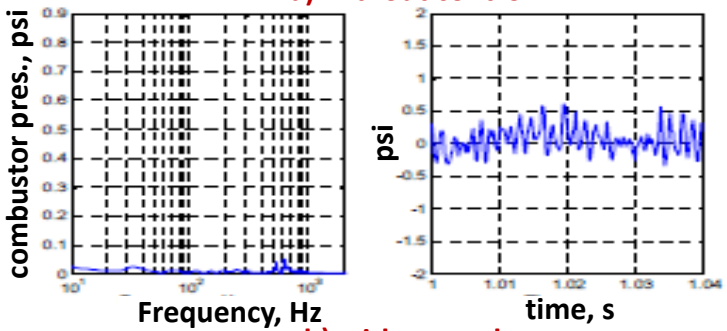
## Testing at NASA GRC 2011




Combustor instability during fuel to air ratio transient

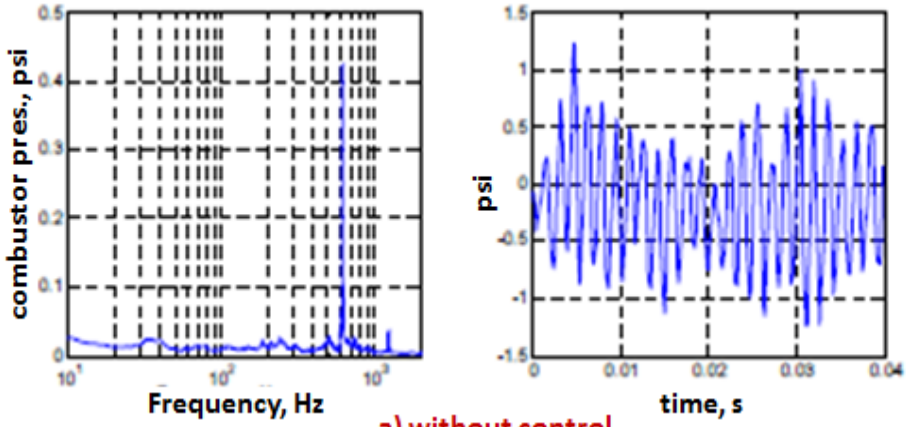



a) without control

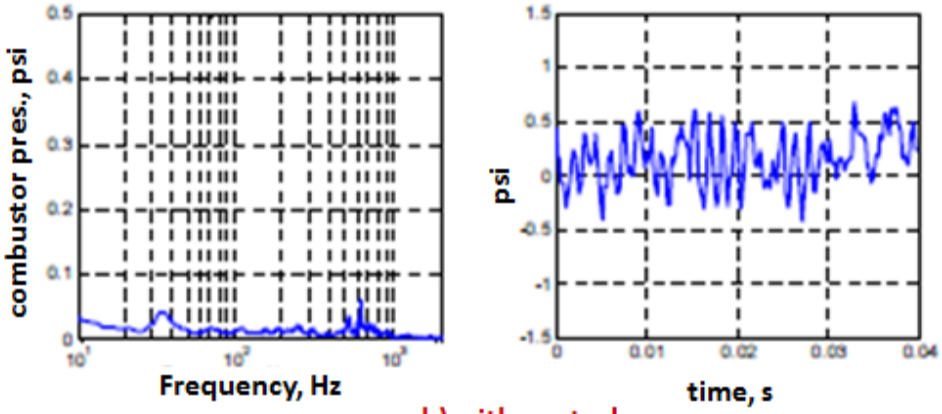



b) with control

## Control by sensing pressure upstream of the Combustor – Less harsh environment for sensors



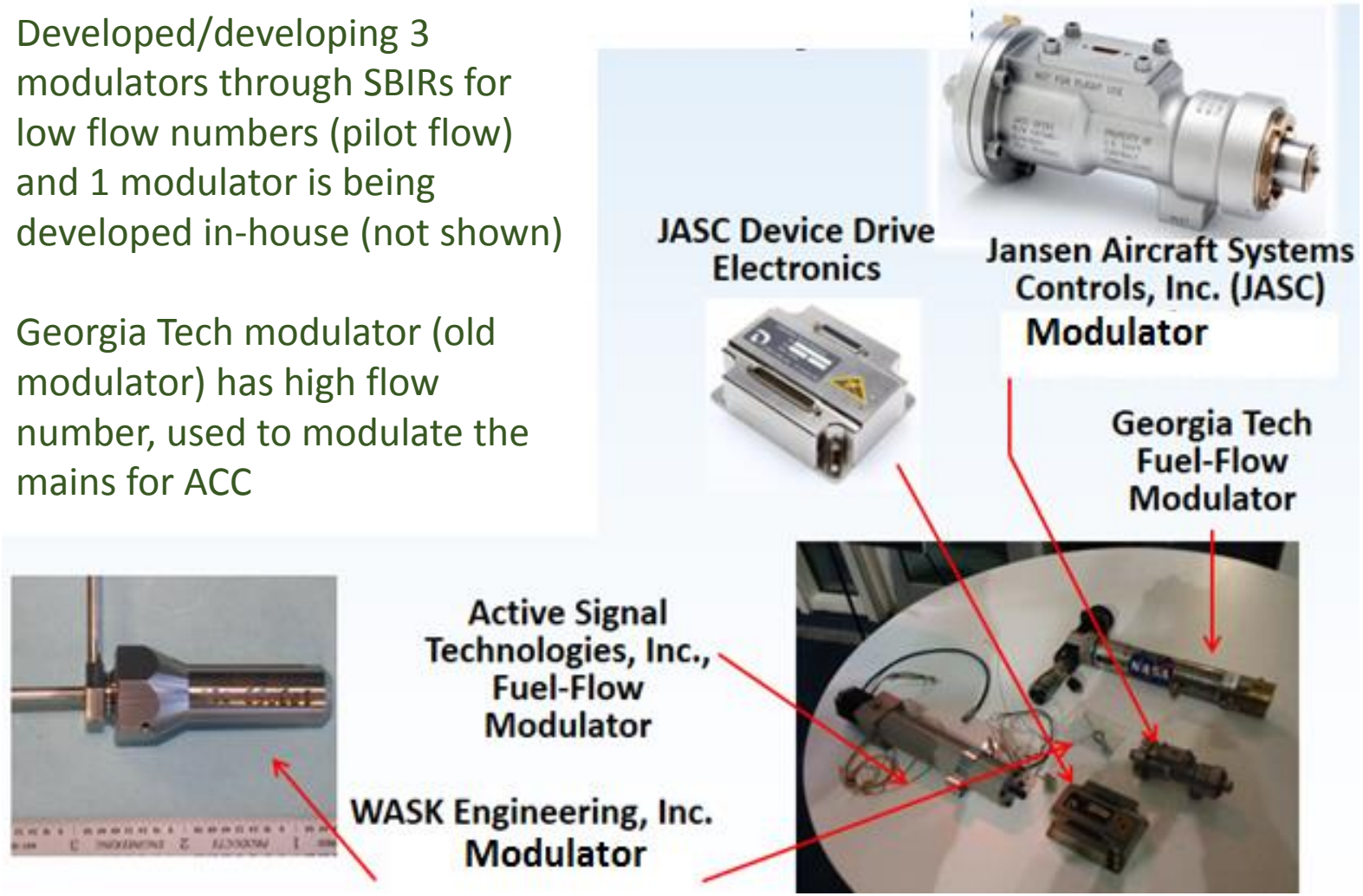

a) without control




b) with control

# Small Fuel Modulator Development w/ Low Flow Numbers

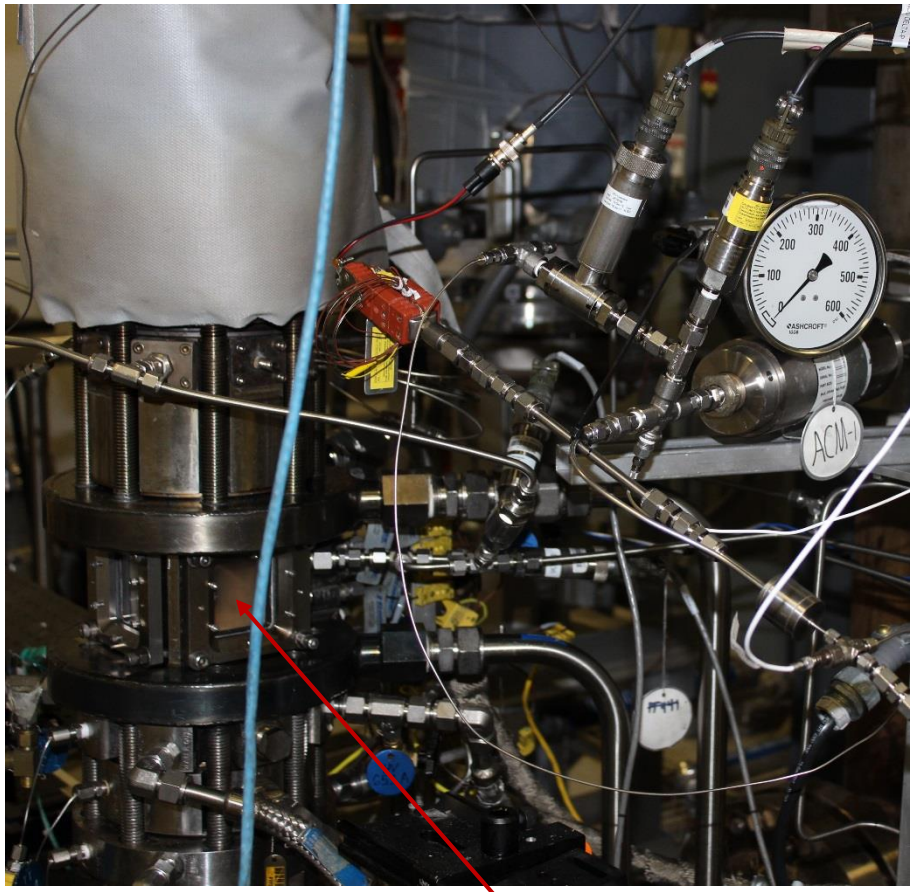
- Objective: develop modulators w/ low flow numbers to modulate pilot flow & small size, w/ higher temperature materials/fuel cooling to potentially integrate with fuel injector assembly in harsh environment – Demonstrate ACC
  - Developed/developing 3 modulators through SBIRs for low flow numbers (pilot flow) and 1 modulator is being developed in-house (not shown)
  - Georgia Tech modulator (old modulator) has high flow number, used to modulate the mains for ACC



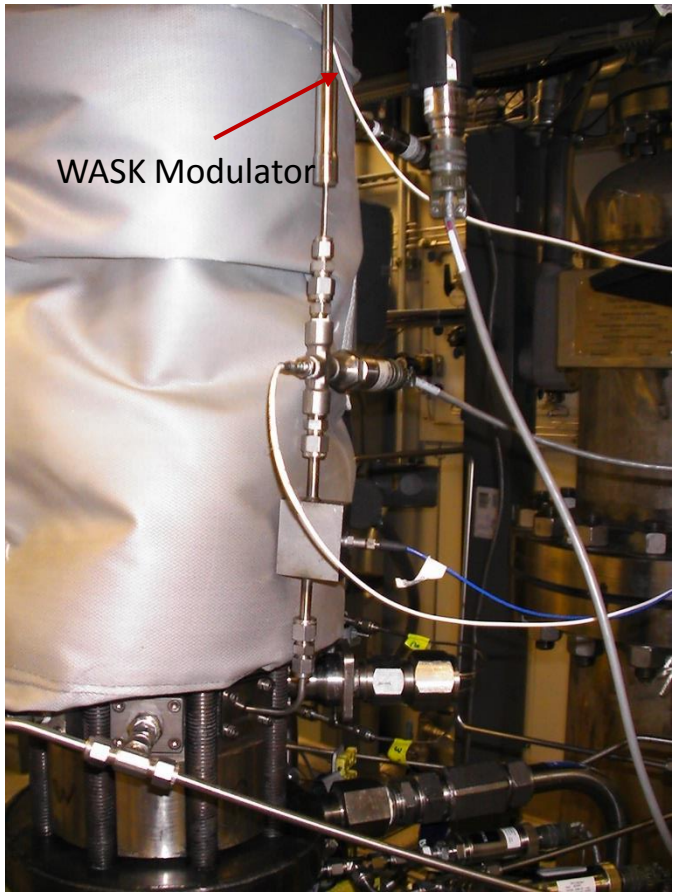
# Fuel Modulator Testing in CE13 Combustor Rig at GRC

**CE13:**
T3: 800° F; P3=75 psi
Fuel flow = 0-2lbm/min

## In-House Modulator Testing

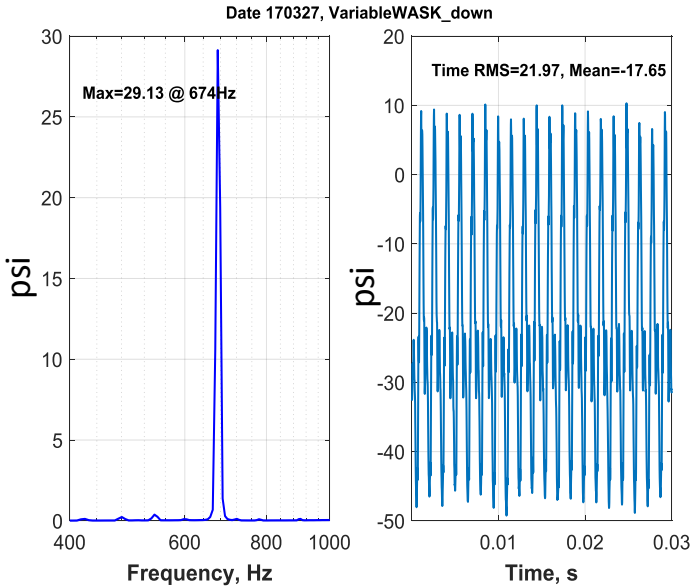



## WASK Modulator Testing

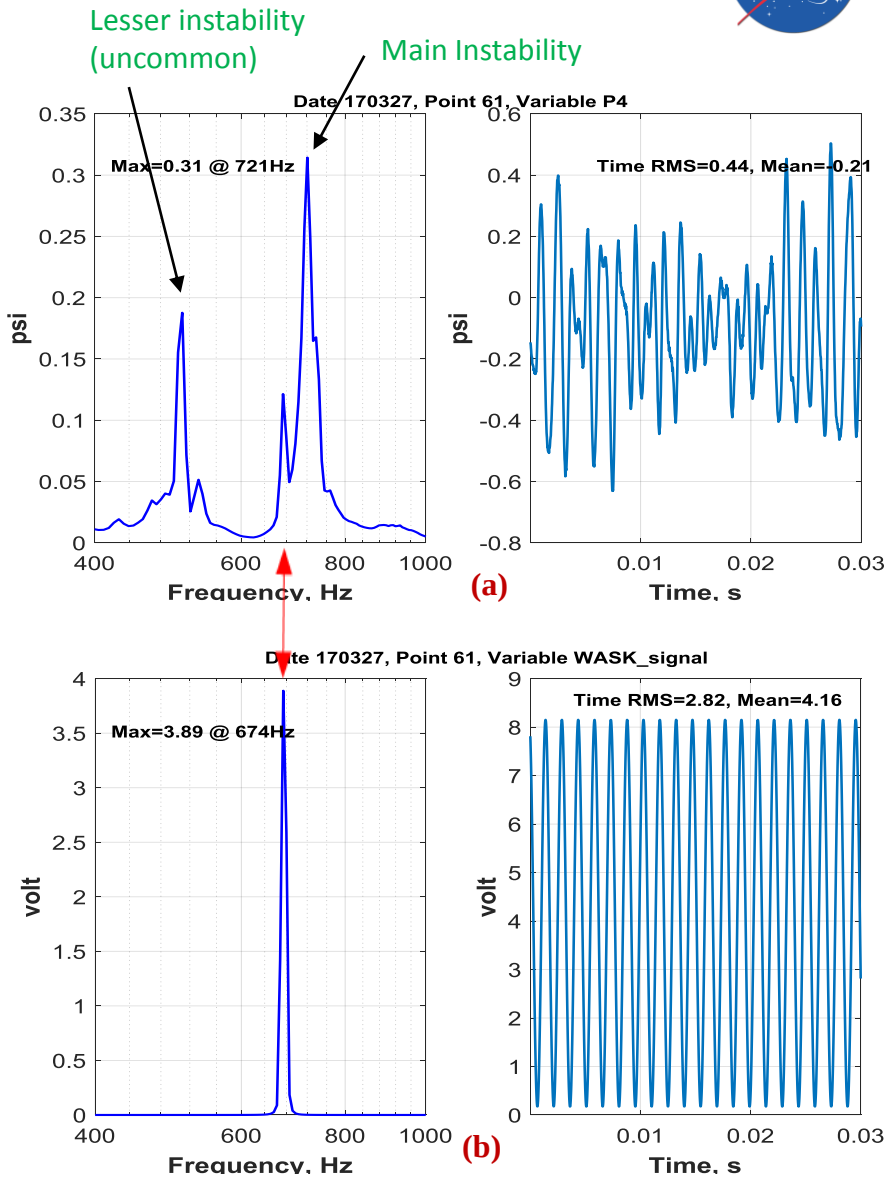


# Fuel Modulator Test Results – CE13

- Modulator setup optimized for short line lengths and for maintaining same flow area
- Modulating the pilot (~25% of fuel) with the WASK valve produced relative strong modulation downstream of the valve (upstream of the combustor).
- Modulating near the instability frequency show instability entrainment – indication that instability can be supressed with closed loop.



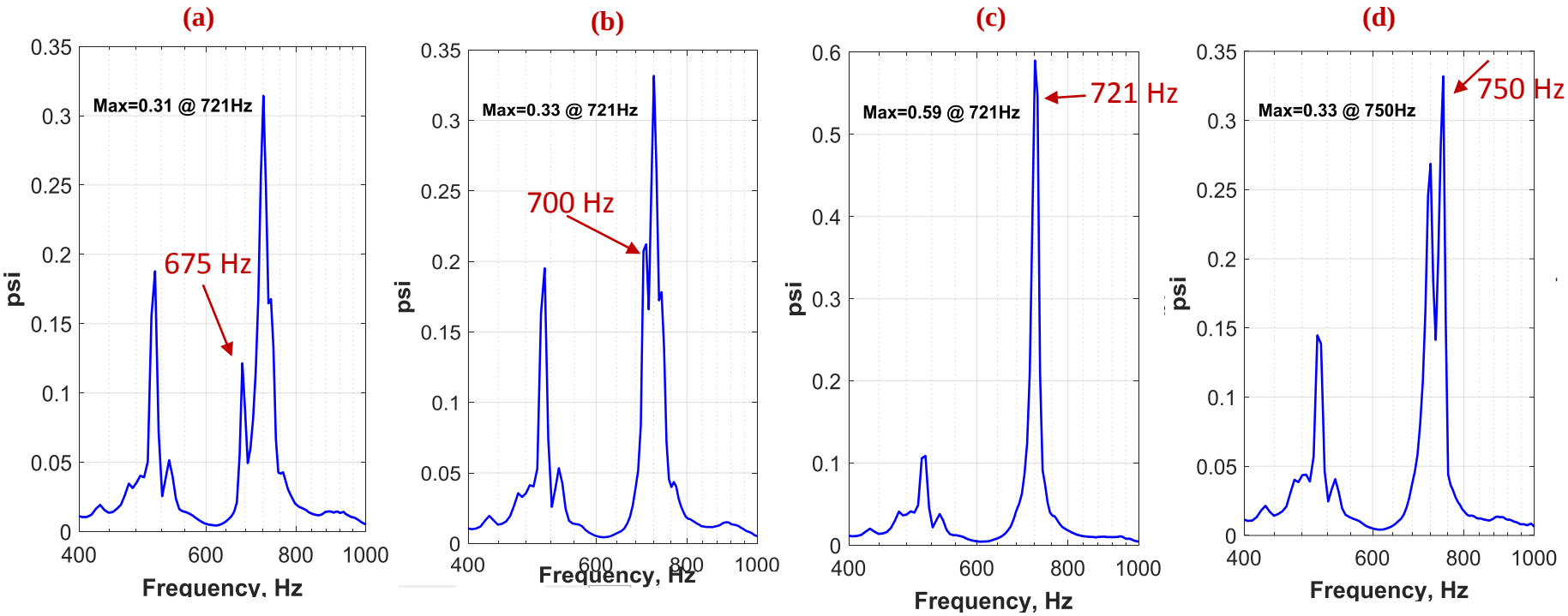

Modulator downstream pressure spectral varied from 25 to 35 psi at different frequencies.




(a) – Downstream Pressure spectral;
(b) - Applied modulator voltage

# Fuel Modulator Test Results – CE13

- As shown in these figures, instability entrainment takes place when modulating near the instability, with progressively increased amount of entrainment nearer the instability frequency. In case (c), the 721 Hz instability is even amplified and the 500 Hz mode is reduced.



# Questions


- What Pratt/UTRC is thinking lately about ACC?

  -- What more can be done or is there something that should be done differently?

  -- Is ACC technology demonstrated so far feasible and how this type of technology can be moved to higher TRL combustors or demonstrations?

  -- What about Sensors for ACC?

  -- Modeling to better understand and model combustion dynamics?

  -- Any thoughts about ACC challenges in supersonic combustion?

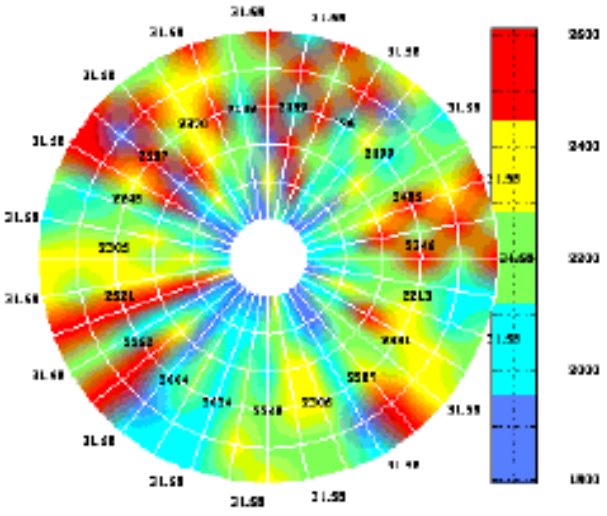
Some of these questions are also of interest to JANNAF - Advance Combustion Control mission area Under Airbreathing Propulsion

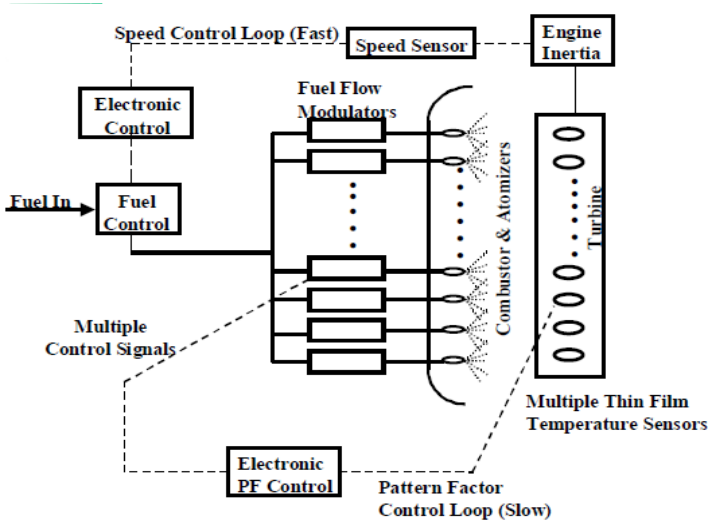
# Burner Pattern Factor Background & Questions

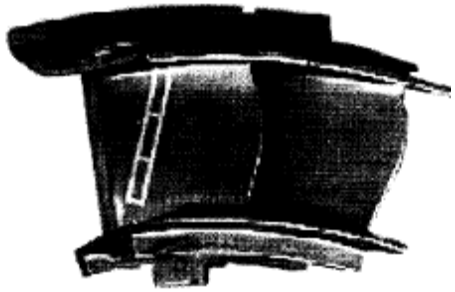
- NASA ACC under NASA AST program in late 90's had a Burner Pattern Factor (PF) element with the objective to develop an active engine fuel distribution system capable of producing a more uniform combustor exit temperature.

- Temperature margin due to PF is approximately 25% and besides reducing NOx and increasing turbine life, more fuel consumption savings can potentially be realized with PF control than perhaps any other engine improvement technology.

- PF control will be in series with ACC – Fuel modulators arranged circumferentially – Total fuel is distributed by individual modulators based on temperature feedback from circumferentially arranged temperature sensors.



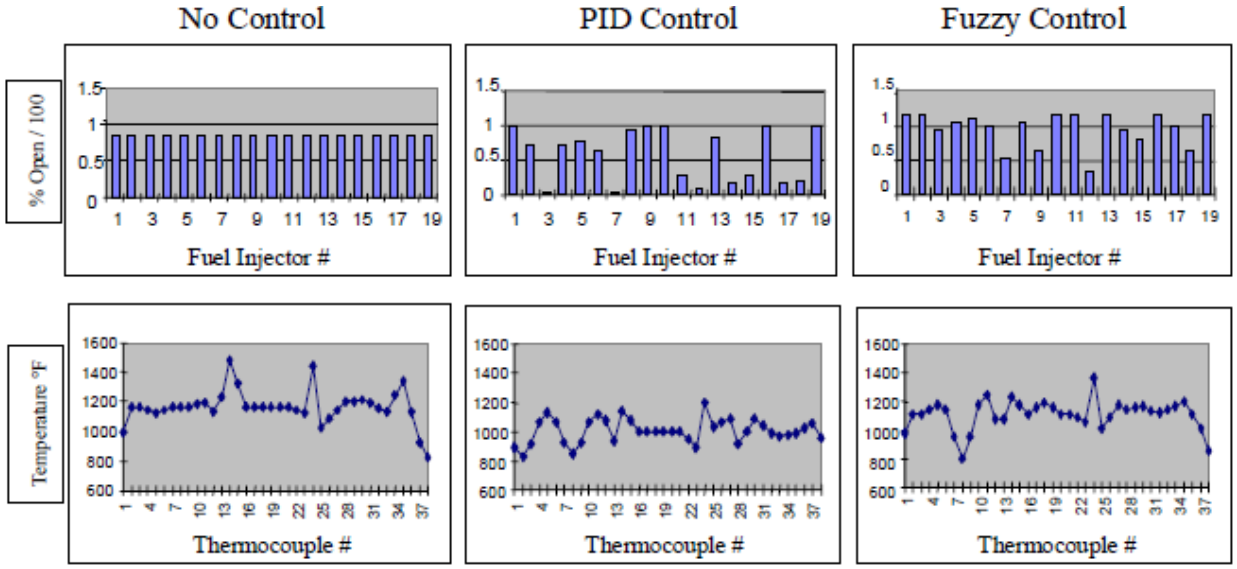


**Shown thin film thermocouple sensor attached to stator vane (photograph by Honeywell) (Platinum-rhodium thermocouples performed better)**

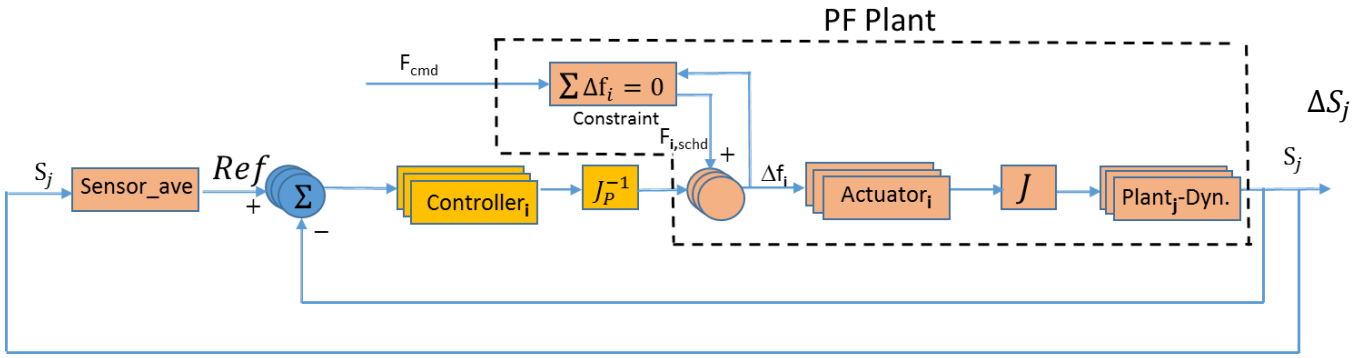
# Burner Pattern Factor Background & Questions

- Experiments Conducted on combustor rig at Honeywell – PF reduction shown – 19 modulators used and 38 sensors




Experimental pattern factor reduction at "medium" power condition

- Recently exploring control approaches for PF using sensors in the turbine stator vanes and alternatively using existing engine EPR sensors




$$\Delta S_j = \sum_i \left(\frac{\partial S_j}{\partial f_i}\right) \Delta f_i = J \Delta f_i$$

One of the possible PF control schemes

# Questions

- What Pratt/UTRC is thinking about Pattern Factor?

  -- Any thoughts about sensors for PF located at the turbine inlet vs. the nozzle inlet?

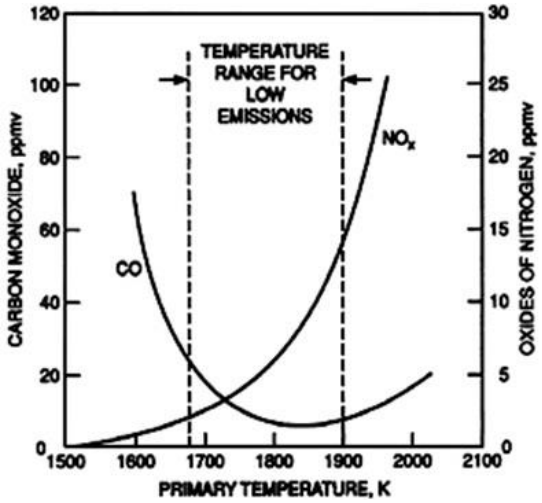
  -- What about sensors technology…is it feasible – for sensors located in the hot zone?

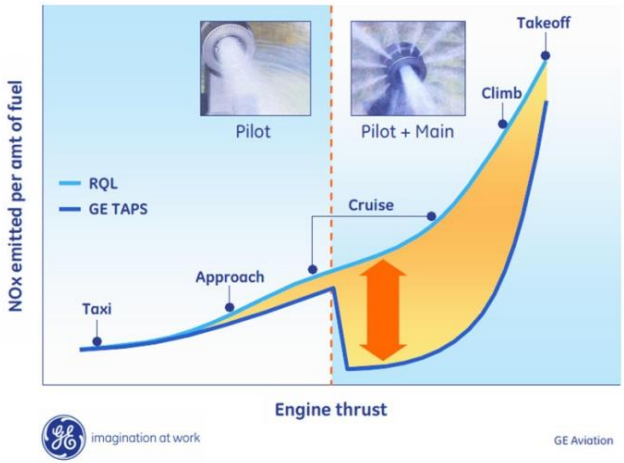
  -- Any thoughts about modeling for PF or setting up a rig?

  -- Would there be interest for us advocate in this area?

Pattern factor is also an interest of JANNAF - Advance Combustion Control mission area Under Airbreathing Propulsion

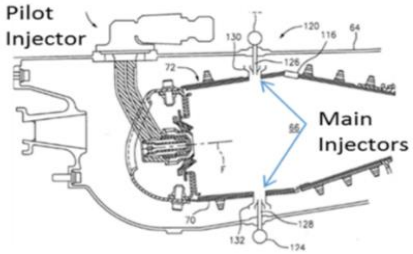
# Emissions Minimizing Controls Background & Questions




Cruise-Level NOx Reduction

P&W ACS Annular Combustor




- Overall there is a sweet spot for emissions reduction and equivalence ratio. However, fuel in the combustor is distributed through staging*, and how this staging is done has influence on emissions and provides opportunity for closed loop emissions minimization

*sequencing of the fuel injection through one or more local injection zones, in order to tailor the fuel-air mixture ratio over a large engine operating (airflow) range.

# Questions

- What Pratt/UTRC is thinking about Emissions Minimizing Controls?

  -- Is there an opportunity in this area and should we advocate for that?

# Conclusions


- Final Thoughts/Follow-up