Intelligent Engine Systems

Relevance/Impact:

- **Enhanced safety of operation**
- **Enhanced off-design performance**
- **Reduced maintenance cost**
- **Enhanced component life**
- **Reduced emissions**
- **Reduced noise**

Projects:

- **Compressor Control (Prasad, Sankar, Neumeier, Dunn)**
- **Combustor Control (Zinn, Seitzman, Jagoda, Neumeier, Menon)**
- **Turbine Control (Dunn, Sankar)**
- **Active Noise Control (Ahuja)**

2.3 Intelligent Engine Systems

2.3.1 Compressor control

Prasad (Ga Tech), Sankar (Ga Tech), Neumeier (Ga Tech), Dunn (Ohio State)

Science & Technology Objective(s):

- Develop innovative controllers for optimization of compressor performance while protecting against catastrophic events.
- Develop a compressor health monitoring system for maximization of operational hours between maintenance while ensuring safety.

Collaborations:

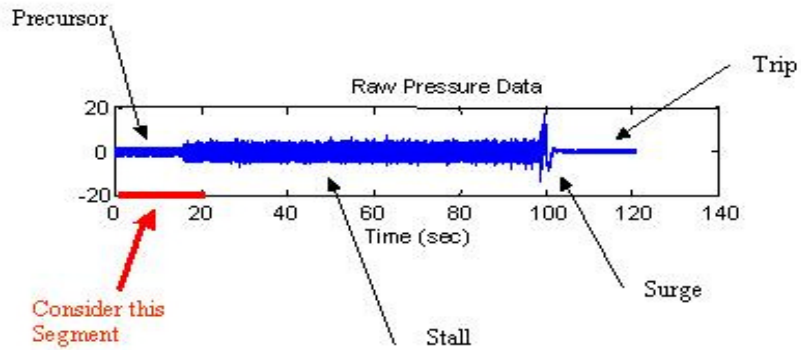
- Government – NASA Glen, AMCOM
- URETI – Ga Tech ASDL
- Industry –GEPS, GE CRD, GEAE, P&W
- Synergism with existing programs – complements active compressor stability management programs at GEAE and GEPS

Proposed Approach:

- Theoretical analysis of precursor waves using low order models calibrated by CFD and experimental data..
- Development and evaluations of real time algorithms for detection of stall/surge precursors in axial and centrifugal compressors.
- Development and evaluations of compressor health monitoring algorithms.
- Development and evaluations of novel controller architectures including active flow and fuel control methods that will combine adaptation with learning to ensure safe and high performance operation.
- Assessment of component- and system-level benefits from the active control schemes.
- Collaborations with industry and govt. labs for technology transitions.

NASA Relevance/Impact:

- Safe and efficient operation
- Increased component life
- Reduced maintenance cost



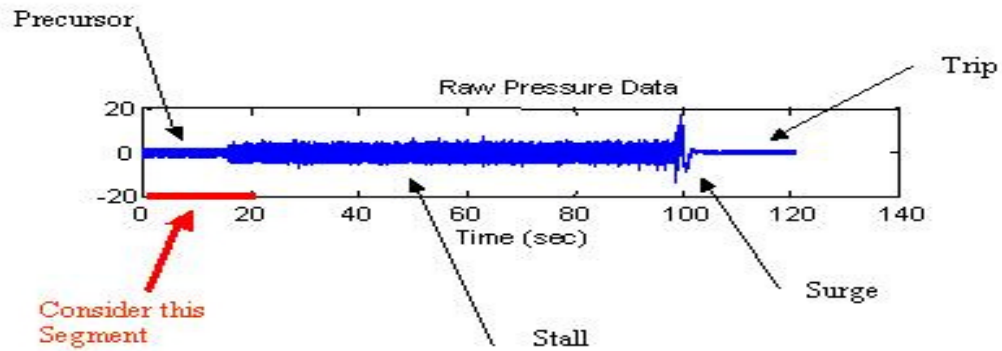
Precursor Detection for Compressor Control

Milestones/Accomplishments:

- Low and high frequency stall/surge precursor characterization in axial and centrifugal compressors.
- Real time low and high frequency stall/surge precursor detection schemes.
- Real time compressor health monitoring schemes for maximization of operational hours between maintenance while ensuring safety.
- Novel active control schemes including active flow and fuel control methods for optimization of compressor performance while protecting against catastrophic events .
- Experimental evaluations using full scale compressor facilities at Govt. Labs and Industry.

Compressor Control

Prasad (Ga Tech), Sankar (Ga Tech), Neumeier (Ga Tech), Dunn (Ohio State)



Precursor Detection for Compressor Control

- **Data obtained on a full scale high pressure-ratio power system compressor shows spontaneous transition from steady condition to rotating stall and subsequent surge, demonstrating a need for active stall/surge margin monitoring.**

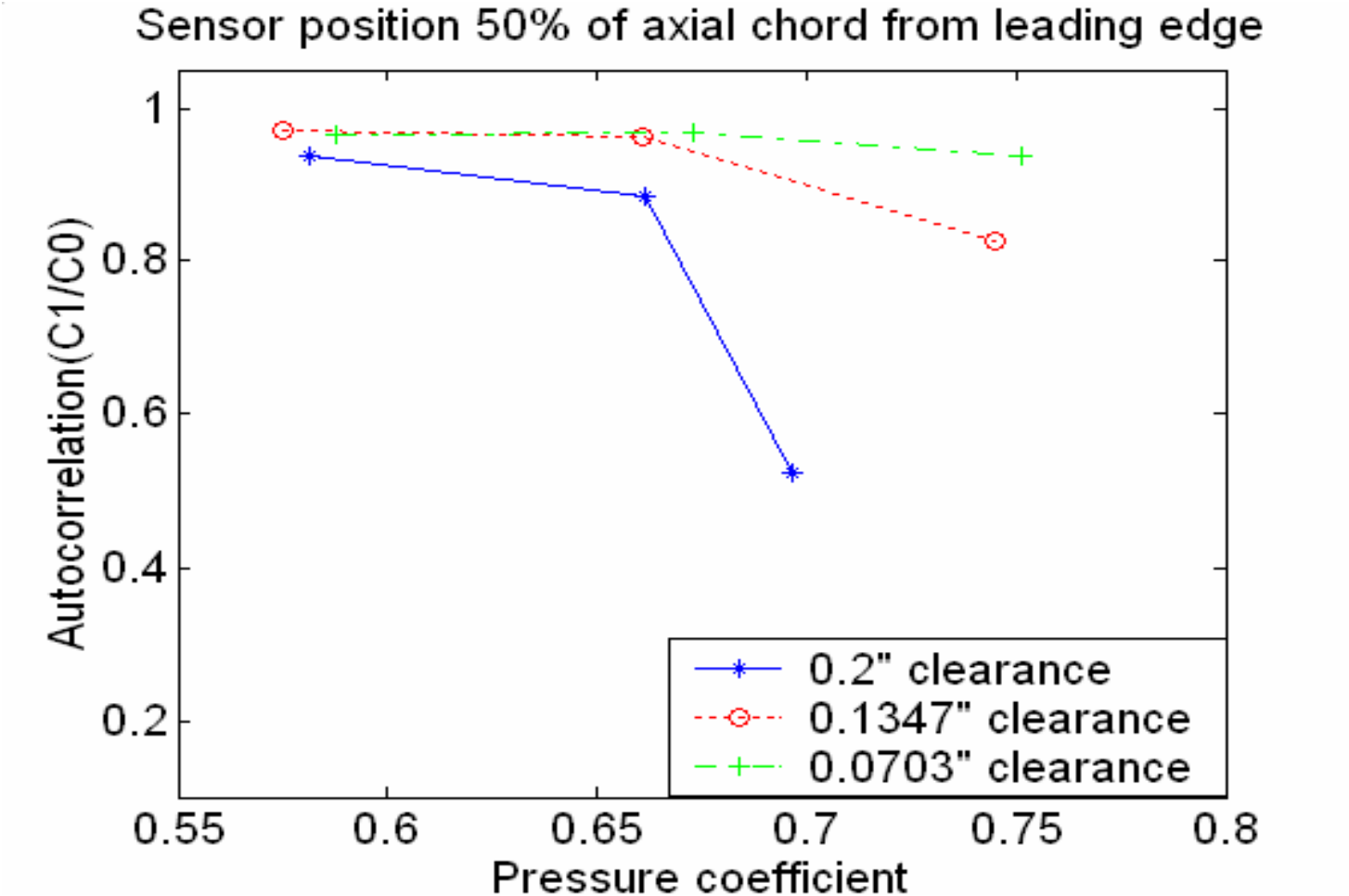
Motivation:

- **High pressure ratios are important for reducing the number of stages in an engine, with attendant reductions in engine weight and size.**
- **Aging and production variability introduce uncertainty in stability margins for safe operation.**
- **Conventional approaches for engine control rely on inter stage bleeding and reactive control strategies, which reduce the efficiency of the system.**
- **Research on efficient and proactive ways for active stability management is needed for ensuring safe and high performance operations of these systems.**

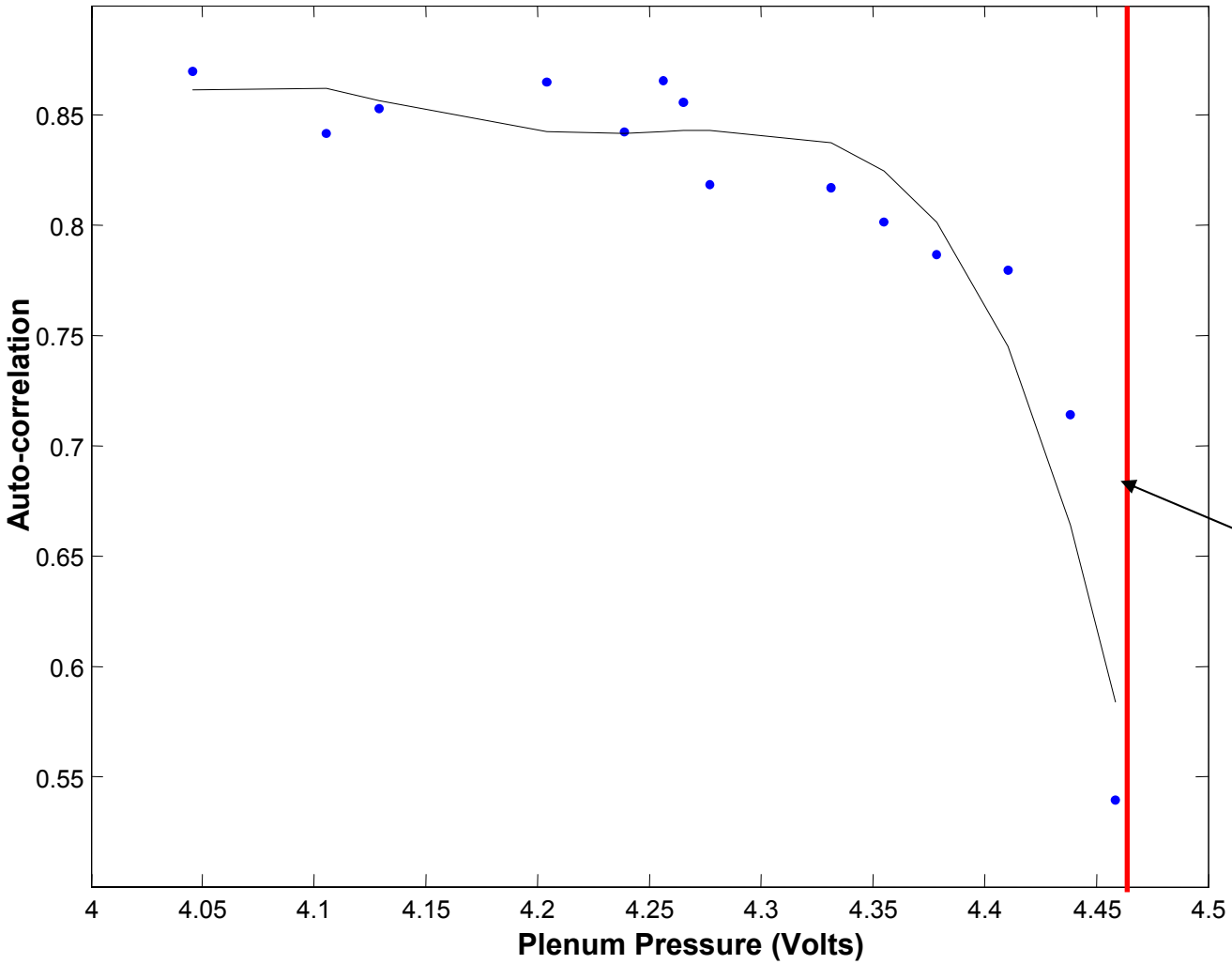
Objectives:

- **Development of innovative controllers for optimization of compressor performance while protecting against catastrophic events.**
- **Development of a compressor health monitoring system for maximization of operational hours between maintenance while ensuring safety.**

Stall Margin Detection Using Over the Blade Dynamic Pressure measurements (in the GE LSRC Facility)



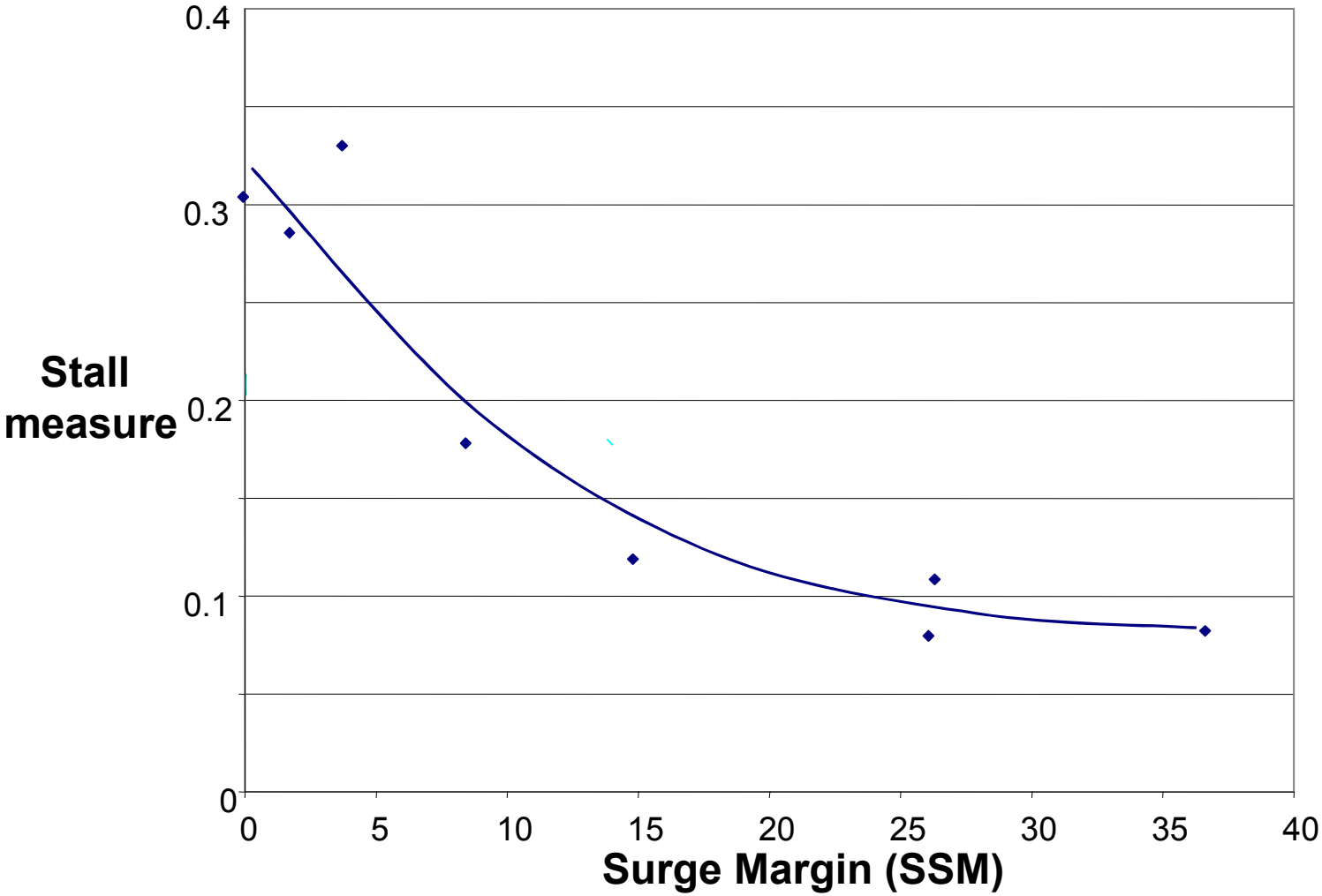
Stall Margin Detection Using Over the Blade Dynamic Pressure measurements (in the GT Compressor Facility)



- **Sensor located above the mid-chord of rotor**

Instability Inception

Commercial Compressor Stall Margin Prediction



- Precursor detection based on over the stator pressure measurements

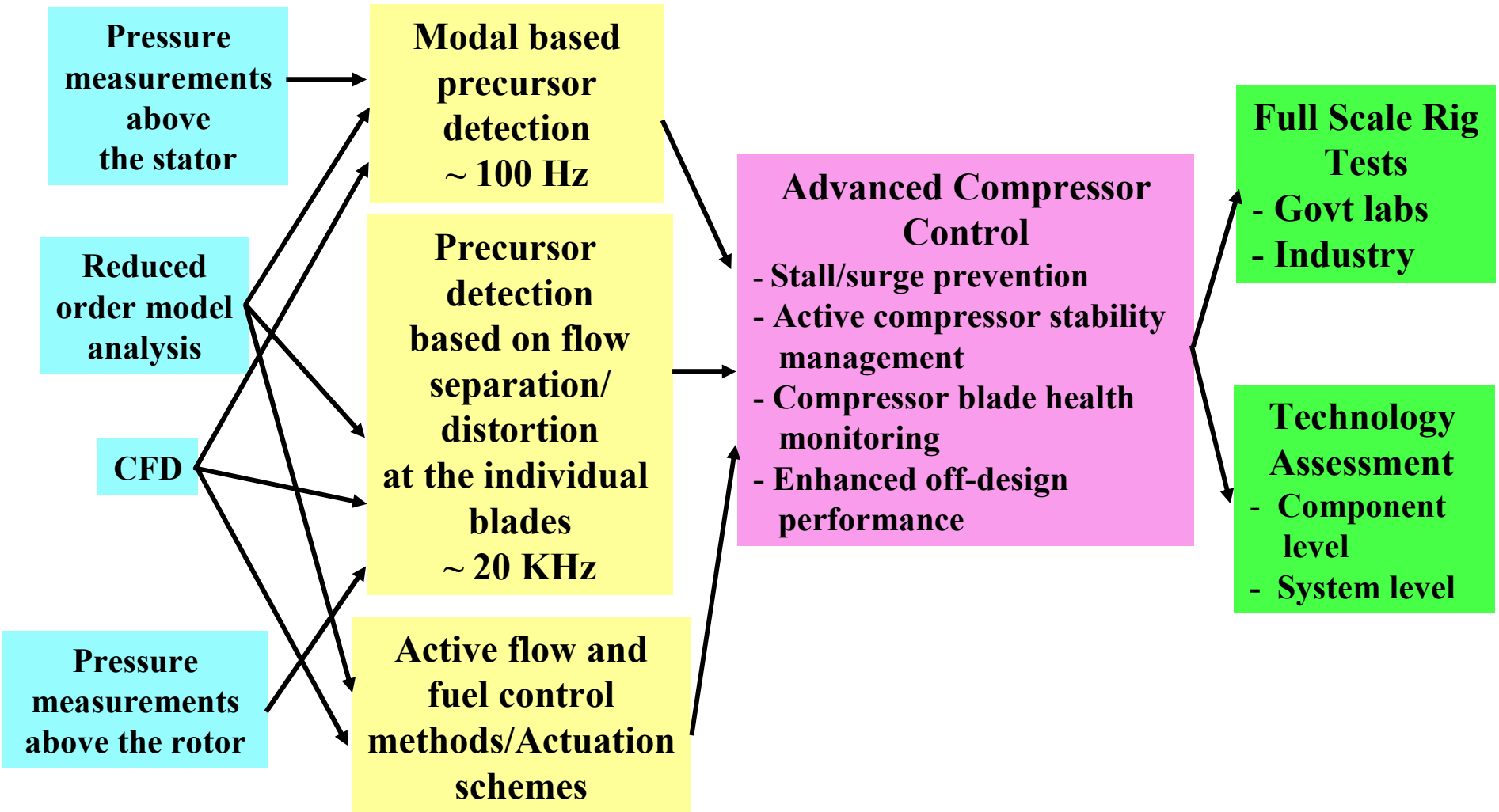
Compressor Control - Proposed Approach

Prasad (Ga Tech), Sankar (Ga Tech), Neumeier (Ga Tech), Dunn (Ohio State)

- Carry out theoretical analysis of both low and high frequency precursor waves using low order models calibrated by CFD and experimental data for compressor operations in both steady state and transient conditions. Establish relationships between precursors and compressor operations.
- Develop and evaluate real time algorithms for detection of low and high frequency stall/surge precursors using pressure data from transducers at the stator and rotor. Algorithm development and initial evaluations will take place using the Ga Tech axial compressor facility. Detailed evaluations will be carried out using full scale compressor facilities at Govt Labs and Industry.
- Develop and evaluate compressor health monitoring schemes using detection and identification of faults through distortions in pressure data. Development of algorithms and initial evaluations will take place using the Ga Tech axial compressor facility. Detailed evaluations will be carried out using full scale compressor facilities at Govt Labs and Industry.
- Develop and evaluate actuation schemes including distributed electromechanical momentum augmenters at the compressor and fuel actuation in the combustor. Controllers will incorporate novel combination of adaptation and learning to ensure safe and high performance operations. Tests on efficacy of zero mass flow actuation will be used to asses the possibility of using combustion driven flow actuation to be developed under a companion effort. The proof-of-concept evaluations will take place using the Ga Tech axial compressor facility. Detailed evaluations will be carried out using full scale compressor facilities at Govt Labs and Industry.
- Carry out technology assessment studies in collaboration with the ASDL at Georgia Tech to assess the benefits form the active control schemes both at the component level and at the overall system level.
- Collaborate with Industry and Govt Labs for transfer of technology.

Compressor Control Project Plan

Prasad (Ga Tech), Sankar (Ga Tech), Neumeier (Ga Tech), Dunn (Ohio State)



2.3 Intelligent Engine Systems

2.3.2 Combustor Control

Zinn, Seitzman, Jagoda, Neumeier, Menon, Georgia Tech

Science & Technology Objective(s):

- Develop intelligent engine systems to:
  1) reduce combustor/engine emissions, NO_x, soot,...
  2) control pattern factor
  3) ensure safe operation and monitor health

Collaborations:

- Government - AFRL
- Industry - GEAE, GEPS
- Synergism with existing programs - current projects in combustor control to prevent LBO and combustion dynamics

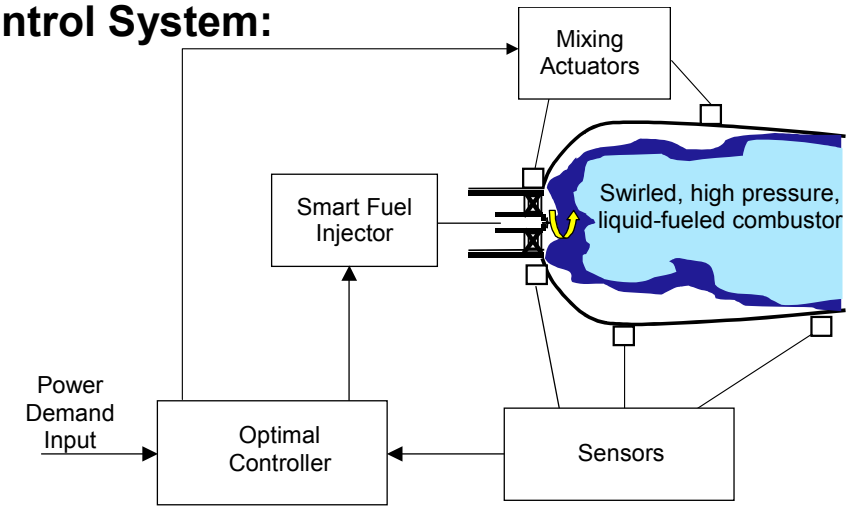
Proposed Approach:

- Develop closed-loop combustor controller to balance goals (reduce emissions, pattern factor, safety)
- Develop practical sensor and data interpretation approaches, including optical and acoustic approaches and MEMS and nanotechnology devices

NASA Relevance/Impact:

- Reduce engine emissions
- Increase safety
- Increase lifetime
- Reduce maintenance costs

Control System:

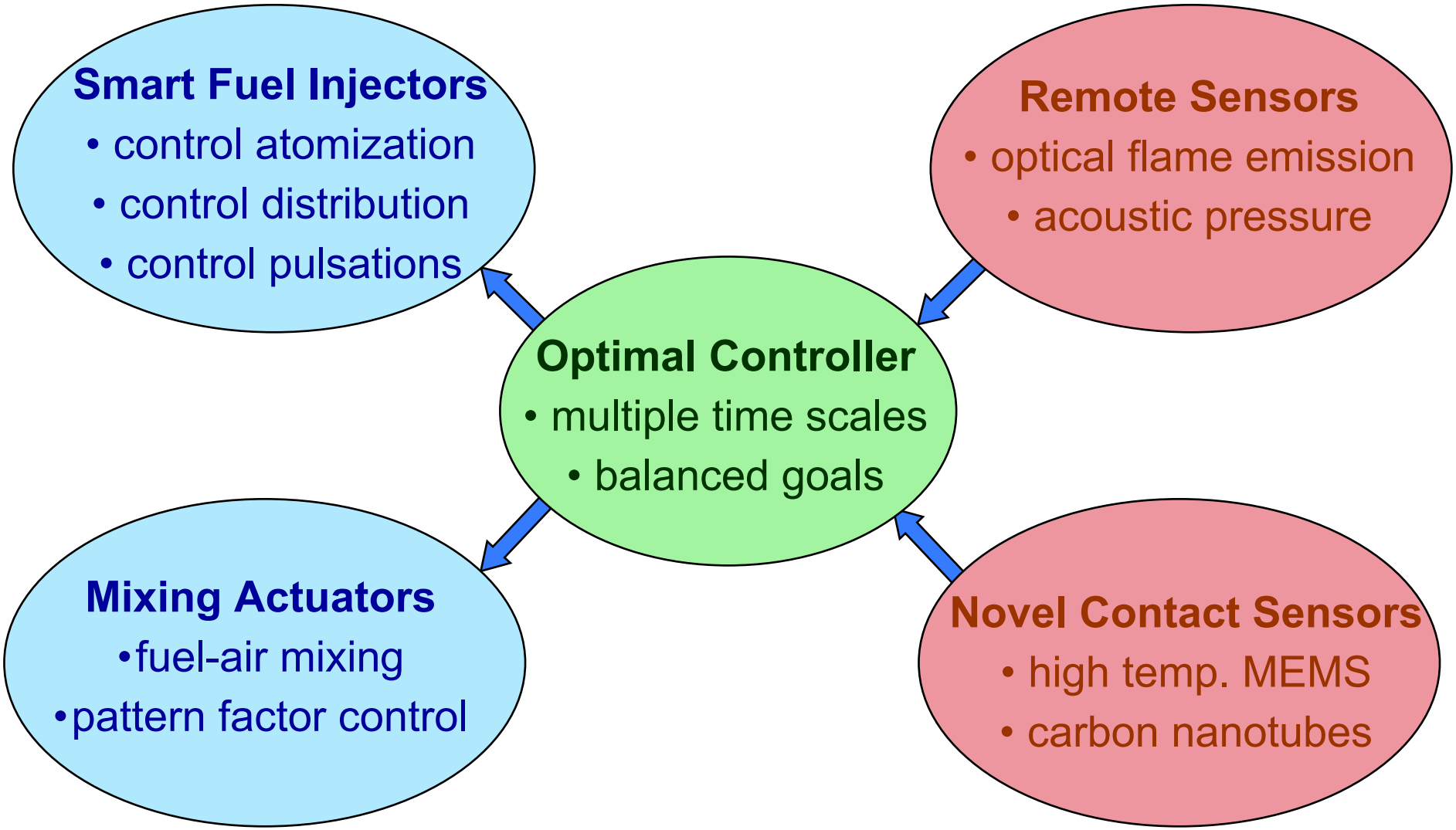


Milestones/Accomplishments (1st 2 Years):

- Develop controllable combustor and smart fuel injector
- Test sensors and develop sensor analysis approach
- Perform controllability tests
- Develop optimal controller

Intelligent Combustor Components

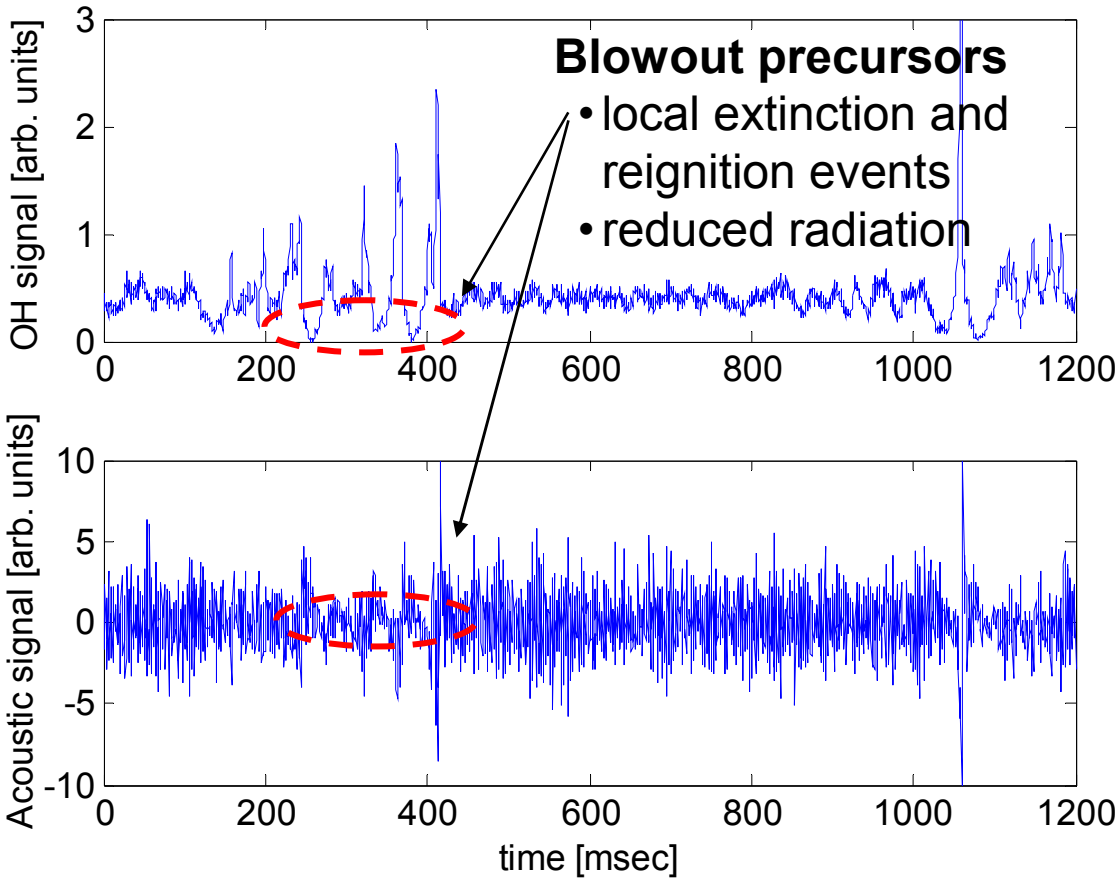
Zinn, Seitzman, Jagoda, Neumeier, Menon, Georgia Tech



Sensor Interpretation Example

Zinn, Seitzman, Jagoda, Neumeier, Menon, Georgia Tech

- Example of ongoing work in detection of blowout precursors



- **Approach**
  - use available sensors but improve data interpretation approaches
  - use multiple sensors and correlations to improve reliability and sensitivity
  - develop new sensors as required