ASCENT Project 055

Noise Generation and Propagation in Advanced Combustors

Georgia Institute of Technology

PI: Timothy Lieuwen

PM: Roxanna Moores

Cost Share Partner/Collaborator: Raytheon Technologies Research Center

Objective:

- Develop and validate physics-based design tools for noise prediction.
- Data generation, benchmarking and validation through a combination of experiments, high-fidelity simulations, and physics-based reduced order modeling.

Project Benefits:

- Industry relevant noise prediction design tool for next generation engines.
- Expected benefits from this work are reduced noise pollution and reduced development time/cost of new engines.

Research Approach:

- **Task 1 – Mechanistic Understanding and Tool Development**
  - Focus on physics of sound generation from the inception of disturbances in the front-end all the way to the far-field perceived noise
  - Combination of experiments, simulation and reduced order modeling
- **Task 2 – Facility Development**
  - Development of complimentary experimental facilities and diagnostic capabilities at GT and RTRC
- **Task 3 – Model Integration and Validation**
  - Collating results from Tasks 1 to create validated prediction models in design tools

Major Accomplishments (to date):

Task-1

- GT measurements and simulations from initial GT rig
- ROM frameworks across the architecture
- Post-processing LES data to inform post-combustor modeling
- Simulations of wave interaction with turbine and combustor rig choke
- Identified and quantified sound power dissipation effects in turbine

Task-2

- GT Facility updates and re-design after initial experiments
- Developed plan to use P&W FAA-CLEEN rig to compliment prior RTRC rig data

Task-3

- Initiated toolchain development for integrating and connecting different ROMs

Future Work / Schedule:

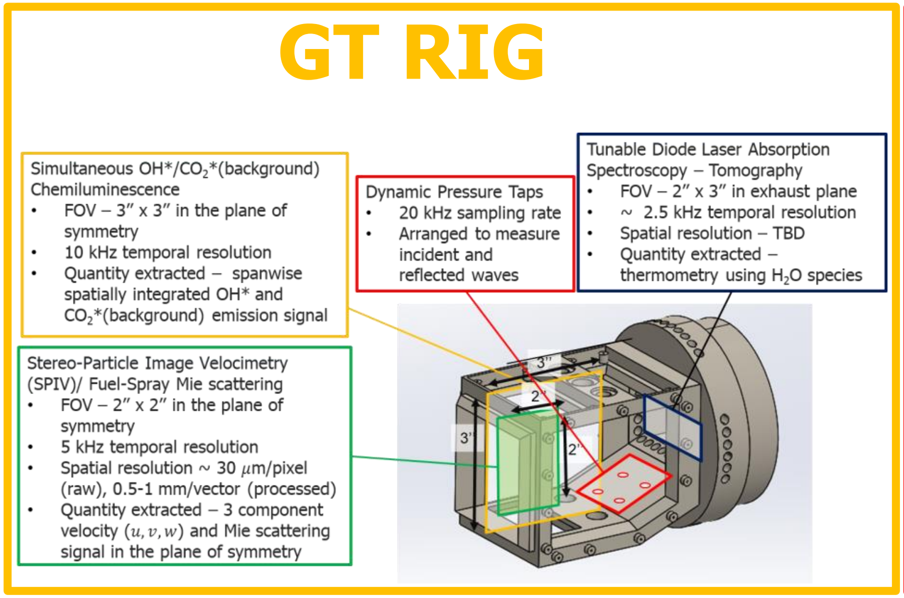
Task-1: Leverage upcoming rig experiments and simulations for improving models. Identify clear input/output from each model piece

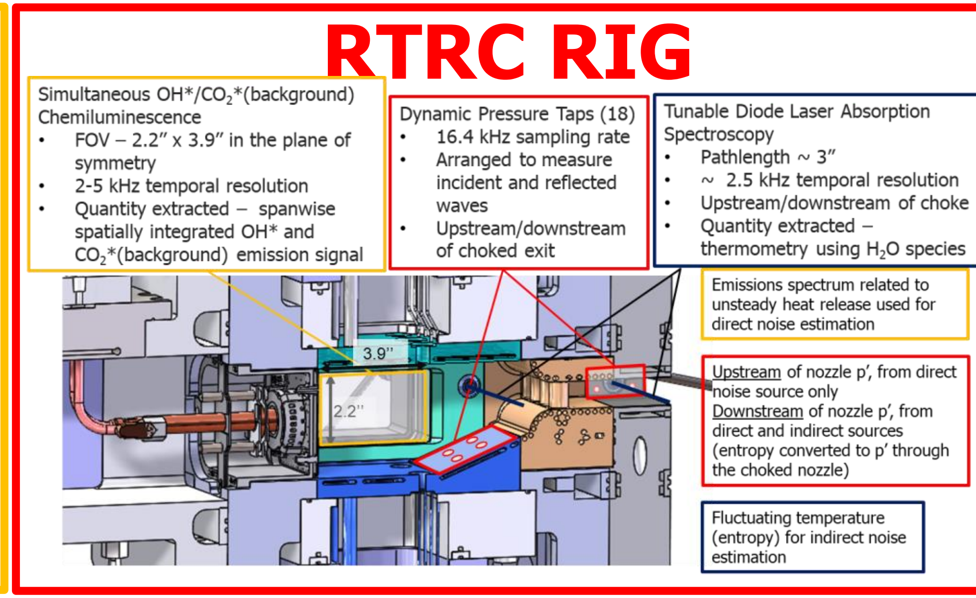
Task-2: GT and RTRC rig measurements from updated/new facilities. New measurements from TDLAS/Dual-TC probes (entropy models)

Task-3: Complete the toolchain integration for combustor and turbine components to estimate far-field noise.

This research was funded by the U.S. Federal Aviation Administration Office of Environment and Energy through ASCENT, the FAA Center of Excellence for Alternative Jet Fuels and the Environment, project 055 through FAA Award Number 13-C-AJFE-GIT-058 under the supervision of Roxanna Moores. Any opinions, findings, conclusions or recommendations expressed in this this material are those of the authors and do not necessarily reflect the views of the FAA.

GT & RTRC Experiment Rigs

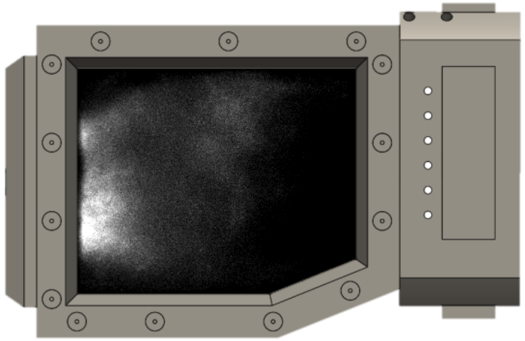


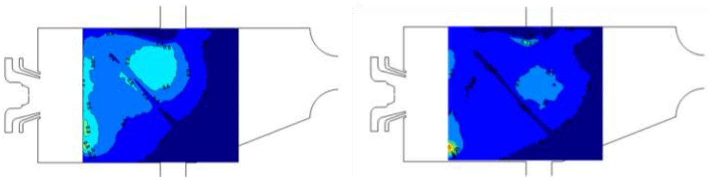


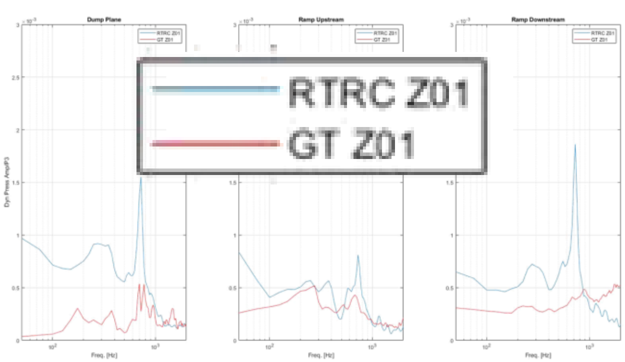
- Complimentary capabilities for the GT and RTRC rigs
  - GT has enhanced optical access
  - RTRC can access higher pressure
  - Tests overlap at approach point
- Validation for GT LES from GT measurements
  - High resolution inputs to both RTRC and GT modeling

Georgia Tech Experiments

Chemiluminescence data processed to assess GT-RTRC rig matching





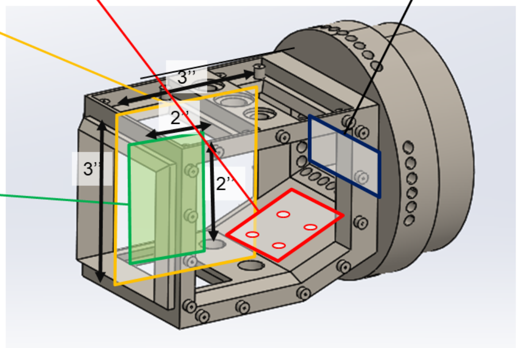


Simultaneous OH^*/CO_2^*(background) Chemiluminescence
- FOV – 3″ x 3″ in the plane of symmetry
- 10 kHz temporal resolution
- Quantity extracted – spanwise spatially integrated OH^* and CO_2^*(background) emission signal

Dynamic Pressure Taps
- 20 kHz sampling rate
- Arranged to measure incident and reflected waves

Tunable Diode Laser Absorption Spectroscopy – Tomography
- FOV – 2″ x 3″ in exhaust plane
- ~ 2.5 kHz temporal resolution
- Spatial resolution – TBD
- Quantity extracted – thermometry using H_2O species

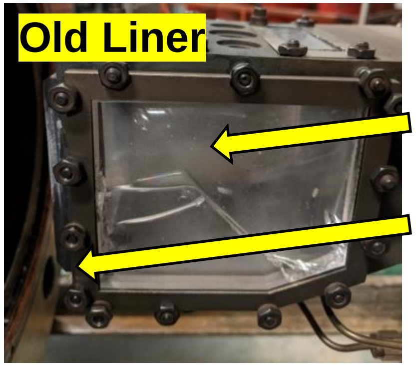
Stereo-Particle Image Velocimetry (SPIV)/ Fuel-Spray Mie scattering
- FOV – 2″ x 2″ in the plane of symmetry
- 5 kHz temporal resolution
- Spatial resolution ~ 30 μm/pixel (raw), 0.5-1 mm/vector (processed)
- Quantity extracted – 3 component velocity (u, v, w) and Mie scattering signal in the plane of symmetry



- Last time, summary of 1st rig entry:
  - Observed significant band of broadband noise
  - RTRC slightly more tonal at lower power, methods in place to control
  - Sensor degradation gives lower GT amplitudes
  - Identified rig improvement
- Re-design and rebuild of the combustor for:
  - better RTRC match
  - better optical access
- Next steps
  - More measurements with updated combustor

Georgia Tech Rig Modification Updates

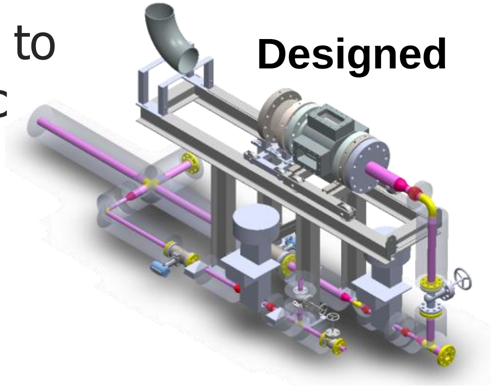
- Re-designed combustor liner for
  - improved optical access
  - Better durability

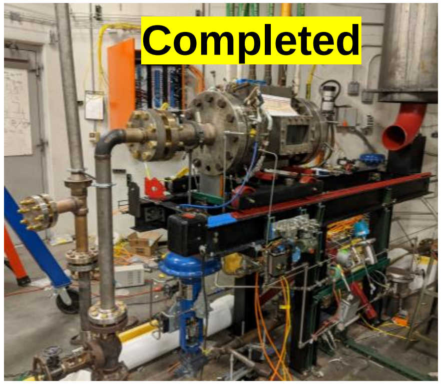


Prone to cracked windows

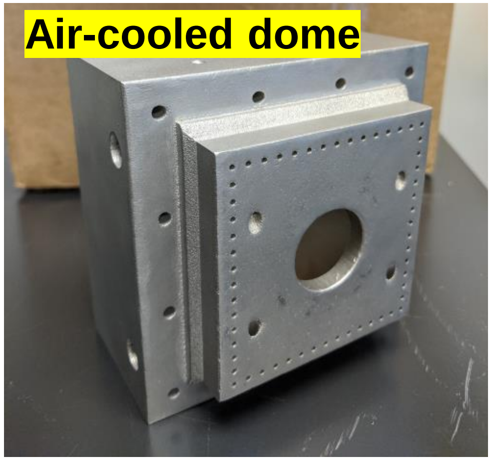
Frame blocked some optical access near swirler

- Re-designed test stand and plumbing to accommodate more optical diagnostic equipment around the rig





- Re-designed the combustor dome to
  - Manage leak paths (better match to RTRC)
  - Add cooling air circuit (better match to RTRC)
  - Accommodate liner with better optical access



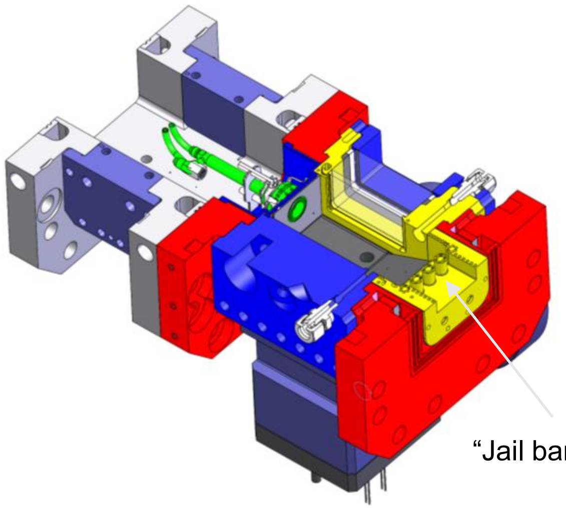
RTRC ASCENT vs CLEEN Rig Comparison

Both RQL designs w/ optical access

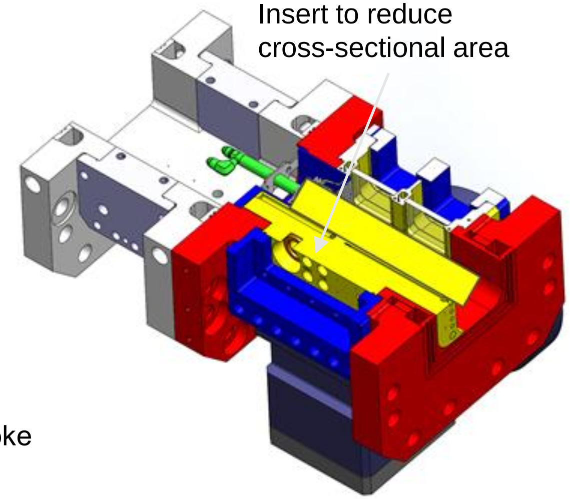
- Air-cooled liners and advanced fuel injector design provide more engine relevant noise data

- CLEEN choke (variable area) is further downstream than ASCENT (fixed area)
- CLEEN has variable length side branch (VRASC) system to vary chamber acoustic resonances

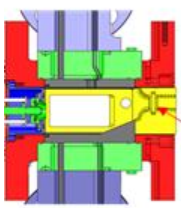
ASCENT Combustor



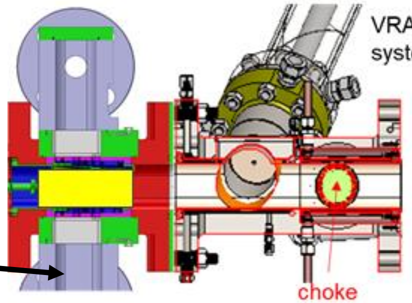
CLEEN Combustor



ASCENT Combustor

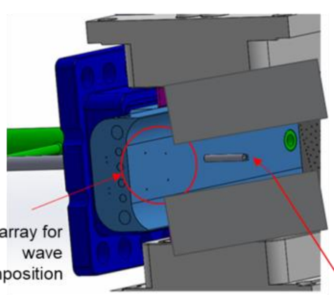


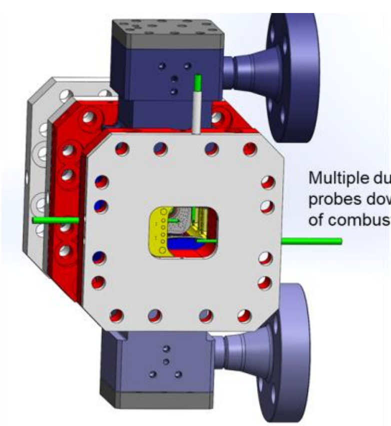
CLEEN Combustor



OD and ID air-cooled liners

- Additional dynamic pressure and temperature sensors

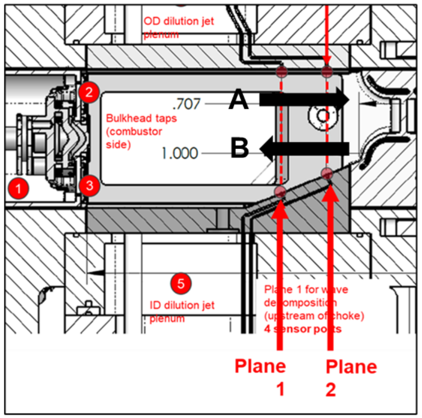




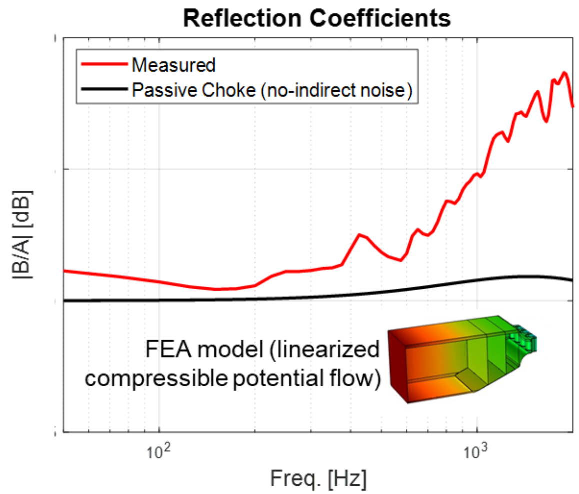
Measured vs Computed Indirect Noise

Wave decomposition using ITP arrays with FEA model of passive choke

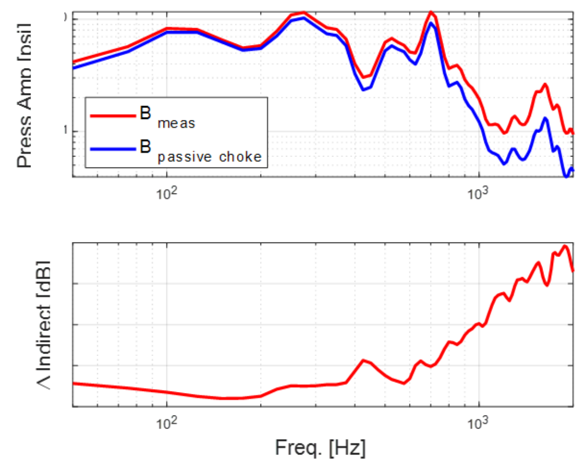
Decompose dynamic pressure to incident (**A**) and reflected (**B**) components
ITP arrays at planes 1 & 2



Compute measure reflection coefficient (**B/A**) and compare with that of a passive choke (FEA model)



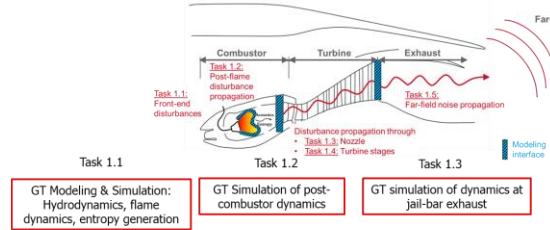
Compute **B** due to passive choke - difference with measured **B** is additional noise due to indirect noise



$$\Delta Indirect\ Noise = B_{meas} - B_{pass}$$

Below ~400 Hz, indirect noise is relatively minor compared with direct noise field

Mechanistic Understanding – GT Progress

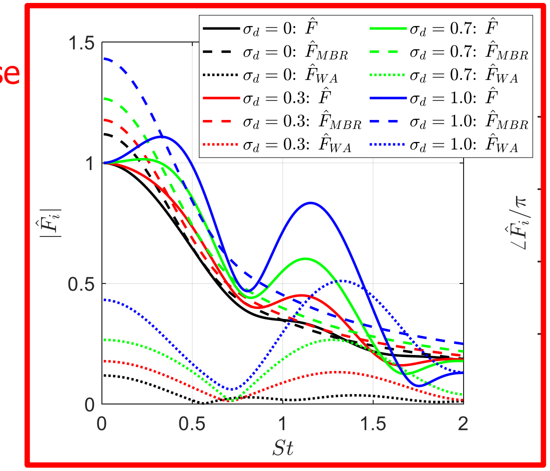


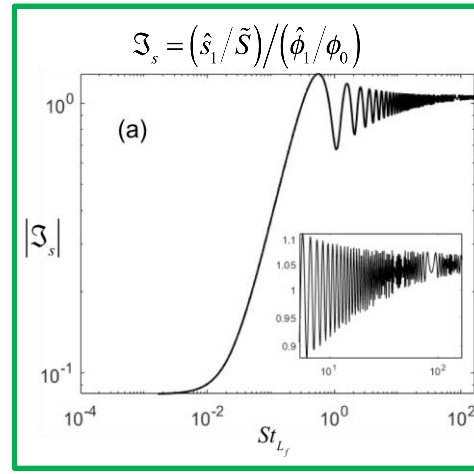
ASCENT
AVIATION SUSTAINABILITY CENTER

- **Tasks 1.1 Modeling Flame Dynamics and Entropy Generation**
  - Understanding contributions to spray flame heat release
  - Entropy source term simplifications for high activation energy cases: integral of q vs integral of q/T

$$\frac{d}{dt}\int_{V(t)} \rho s\, dV + \int_{A(t)} \rho s(u-u_s)\cdot \vec{n}\, dA = \int_{V(t)} \frac{\dot{q}'''}{T}\, dV = \frac{1}{T_b}\int_{T_u}^{T_b} \dot{q}'''\, dT + O(e^{-\beta})$$

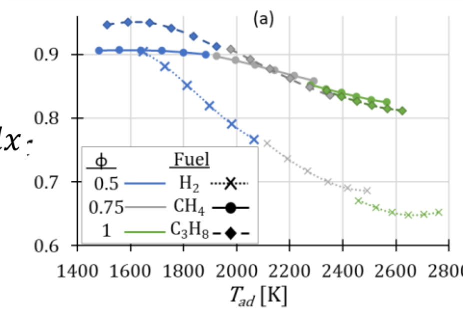
  - Fuel effects on heat release as the dominant source term for entropy generation
  - Non-isothermal effects on entropy generation for premixed and non-premixed flames: velocity fluctuations do not result in entropy generation, but mixture fluctuations cause entropy generation





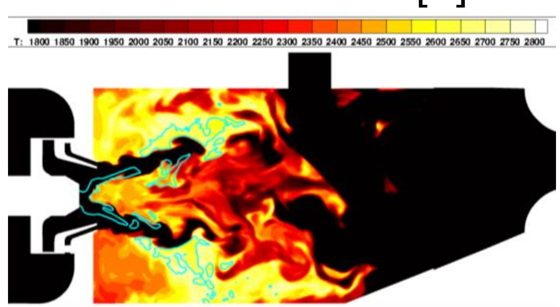
- **Tasks 1.2 Modeling Near-Flame Entropy Evolution**
  - Transfer function input modeling from entropy generation to RTRC post-combustor entropy evolution model

$$\kappa = \frac{1}{T_b}\int \dot{q}'''\, dx \Big/ \int \frac{\dot{q}'''}{T}\, dx$$

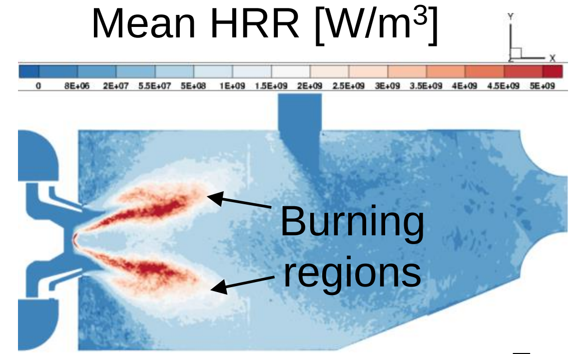


- **Tasks 1.1-1.3 High-fidelity simulation**
  - GT rig (plenum to exhaust) reacting spray LES with updated BC/IC
  - Ongoing post-processing to analyze combustion noise sources
  - Future work to compare with data

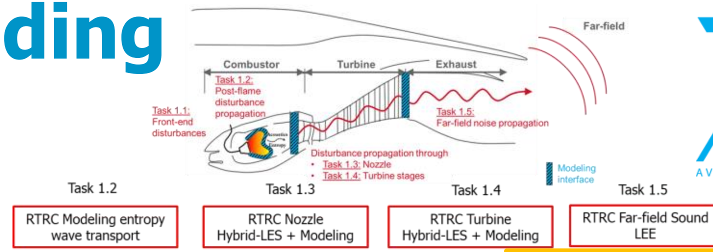
Instantaneous T [K]



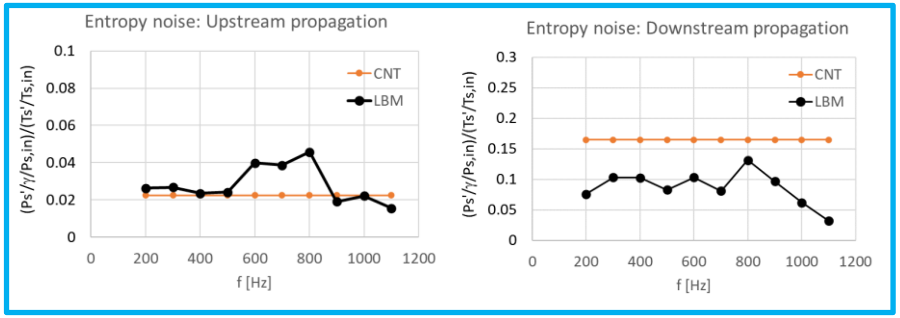
Mean HRR [W/m³]

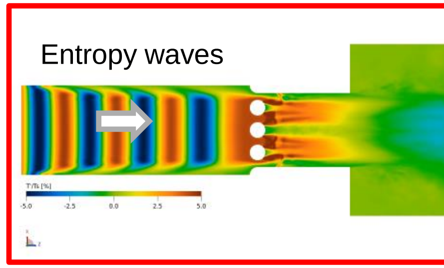


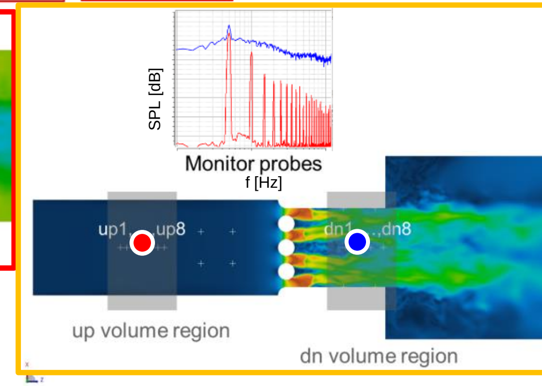
Mechanistic Understanding – RTRC Progress



- **Tasks 1.2 Post Flame Combustor Dynamics**
  - Entropy wave interactions with choke: LBM simulations
  - Wave separation analysis to extract pressure amplitudes of upstream and downstream propagating noise
  - Comparisons with Compact Nozzle Theory (CNT)

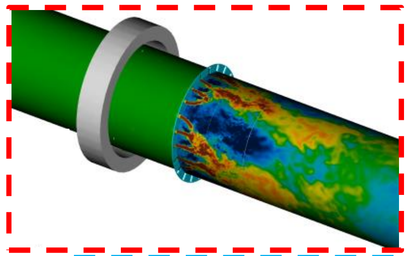


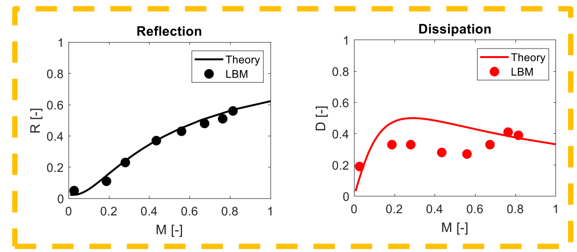


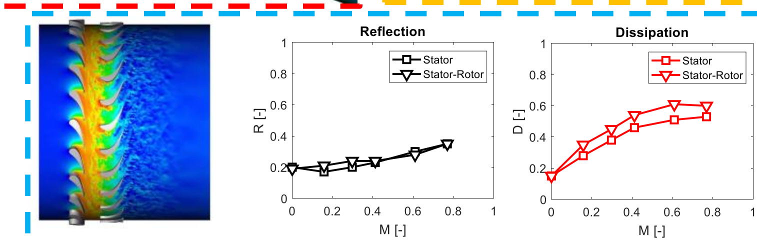


- **Tasks 1.3 and 1.4 Turbine Nozzle and Stage Interactions**
  - Canonical simulations: Major sound dissipation mechanism identified, Conversion of acoustic energy into vortical motion
  - Compared LBM results with theory
  - Application of theory to turbine

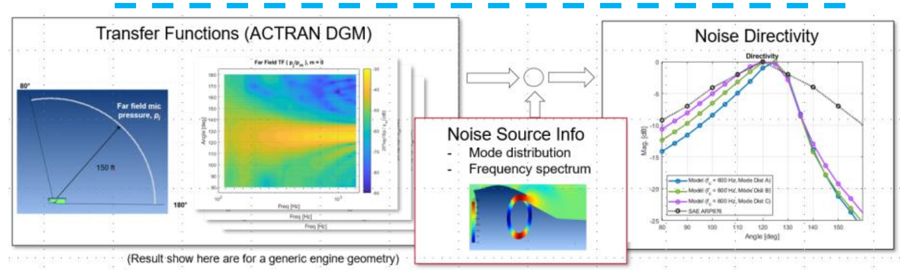
  - Demonstrated that up to 60% of the incoming sound power gets dissipated in the turbine





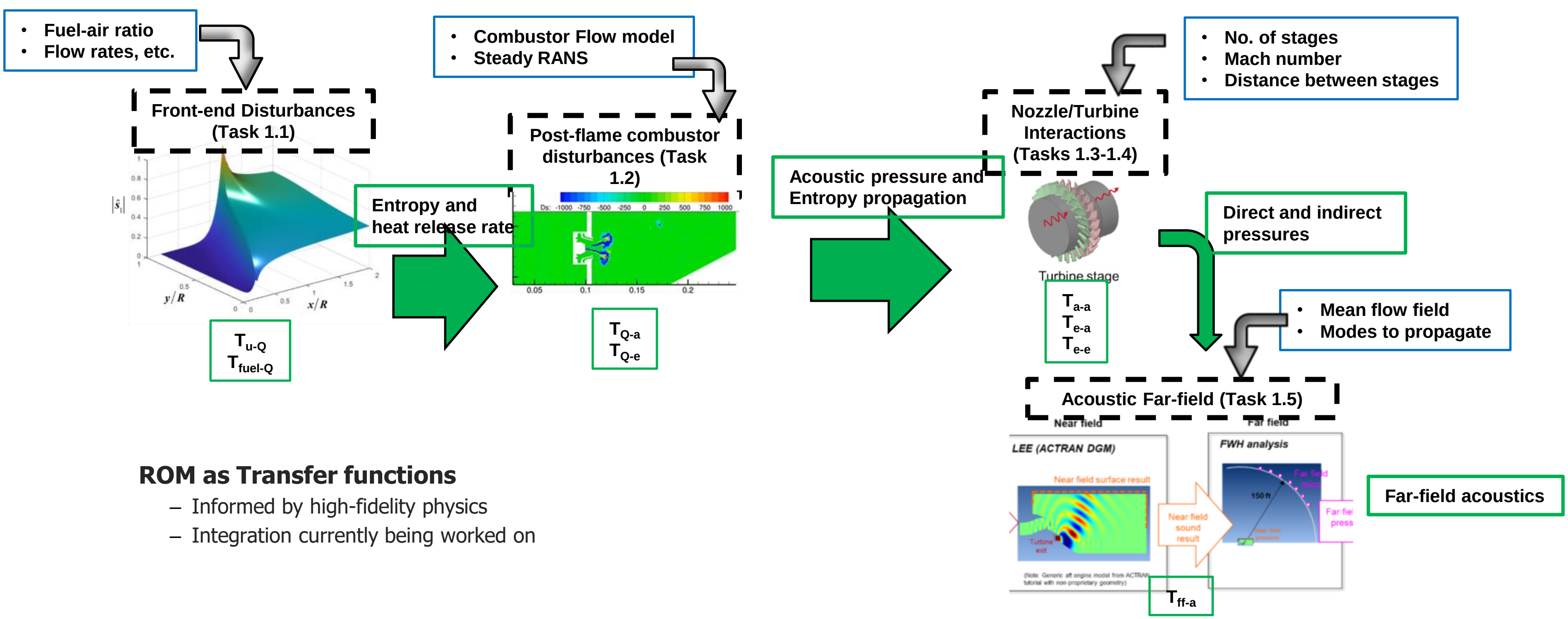


- **Task 1.5 Far Field Sound Propagation**
  - Developed high fidelity far field noise propagation modeling tool chain
  - Demonstrated far field directivity calculation and compared against literature data



Model Integration/Toolchain Development

- Toolchain for physics-based combustor noise prediction at design stage
- Physics-based Predictive Tool
  - Sufficiently simple to execute in a timely manner for quick impact studies
  - Capture relevant physics for broad-band combustion noise
  - Far-field noise impact assessment when combined with ANOPP (or other similar tools)



ROM as Transfer functions

- Informed by high-fidelity physics
- Integration currently being worked on

Summary of Progress and Future Work

- Measurements
  - GT rig
    - Initial campaign provided flame and pressure data
    - Identified required improvements for
      - Better match with RTRC
      - Better optical access
      - Additional measurements and quantities
  - RTRC rig
    - 1st rig entry provided flame and pressure data at elevated conditions
    - 2nd rig campaign will use CLEEN program rig: earlier availability, addresses effects of design; links CLEEN with ASCENT 55.

- Simulations
  - GT LES framework established for reacting cases matching GT rig
    - On-going work to post-process, benchmark with measured data
  - RTRC LBM simulations for fidelity of reduced order models
    - Confidence in applicability of ROMs

- Toolchain development
  - Modeled as a series of linked transfer functions
    - Ongoing efforts to establish and understand input(s)/output(s) connections across transfer functions
  - Future work will benchmark individual TFs using simulation and measurements