ASCENT Project 055

Noise Generation and Propagation in Advanced Combustors

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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 (Years 1-2)**
  - 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 (Year 1)**
  - Development of complimentary experimental facilities and diagnostic capabilities at GT and RTRC
- **Task 3 – Model Integration and Validation (Years 2-3)**
  - Collating results from Tasks 1 to create validated prediction models in design tools

Major Accomplishments (to date):

Task-1

- Identified reduced order models for various regions of engine architecture and physics.
- Initial simulations for cold and reacting flow
- Initial workflow for use of measurements in models

Task-2

- Developed and fabricated GT and RTRC facilities
- Initial measurement campaigns completed in both facilities

Task-3

- Identified benchmarking and validation targets to connect measured data to simulations to reduced order models.

Future Work / Schedule:

Task-1: Incorporate measured/simulated data as inputs into models. Connect model input/outputs between sequential tasks/physics. High-fidelity simulations and validation of simulation data

Task-2: Additional measurements from experiments to complete campaign

Task-3: Benchmarking reduced order model assumptions from comparison between reduced order model predictions and measurements.

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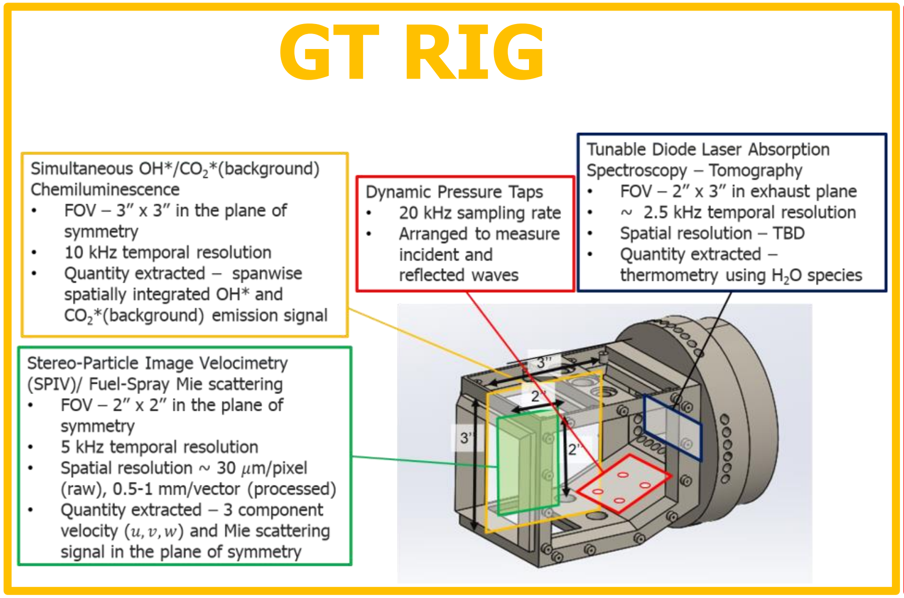
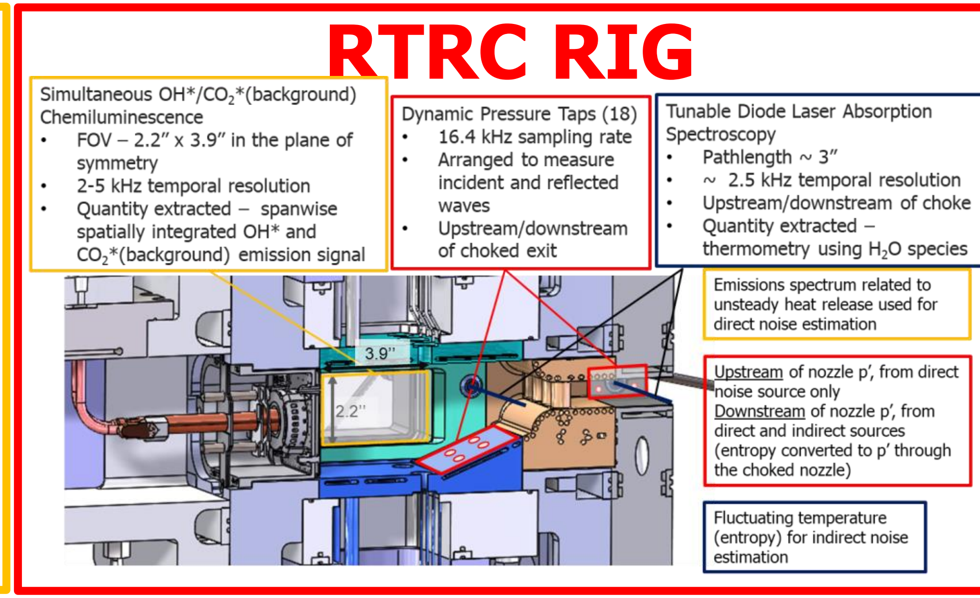
GT & RTRC Experiment Rigs



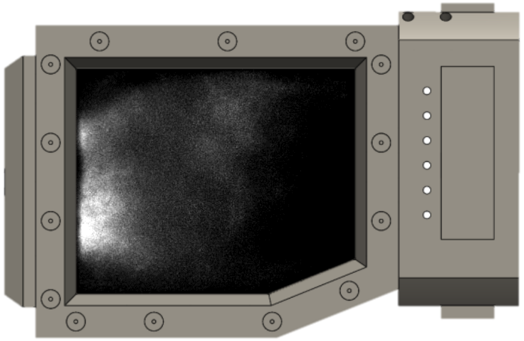


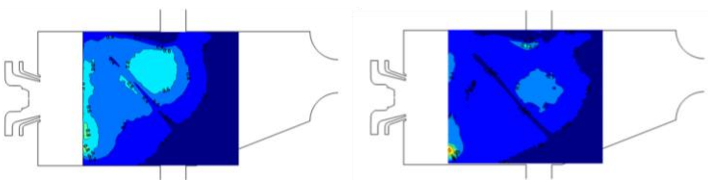
- Complimentary capabilities for the GT and RTRC rigs
  – GT has enhanced optical access
  – RTRC can access higher pressure
  – Tests overlap at approach point

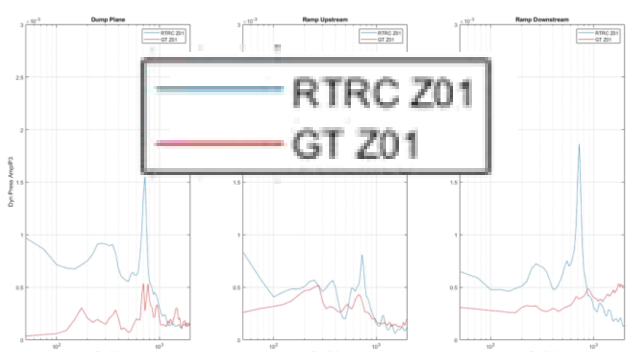
- Validation for GT LES from GT measurements
  – High resolution inputs to both RTRC and GT modeling

Georgia Tech Measurements

Chemiluminescence data processed to assess GT-RTRC rig matching





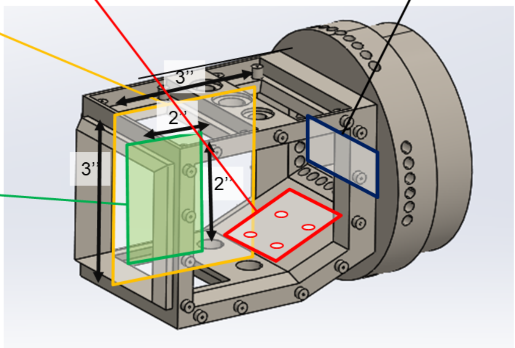


Simultaneous OH*/CO_2*(background) Chemiluminescence
- FOV – 3″ x 3″ in the plane of symmetry
- 10 kHz temporal resolution
- Quantity extracted – spanwise spatially integrated OH* and CO_2*(background) emission signal

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

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

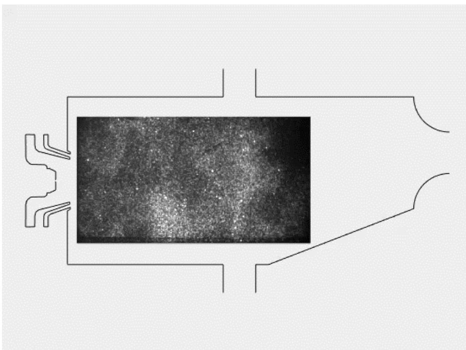


- Observe significant band of broadband noise
- Good acoustic match to RTRC
  - RTRC slightly more tonal
  - Sensor degradation gives lower GT amplitudes
- Next steps
  - Calibrate sensors
  - Improve rig to better match RTRC
  - Detailed diagnostic measurements (T' for entropy mode analysis)

RTRC Measurements

Chemiluminescence data

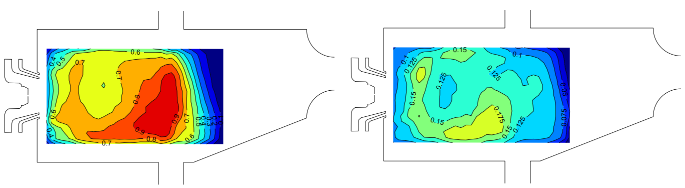
High speed video



1st order statistics

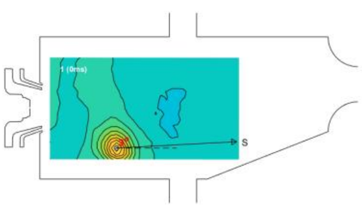
Mean HR

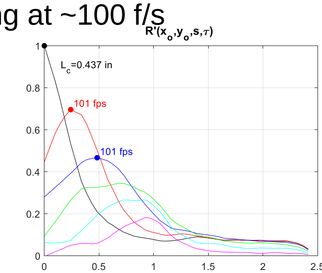
RMS HR



2-point correlation shows dissipating structure convecting at ~100 f/s

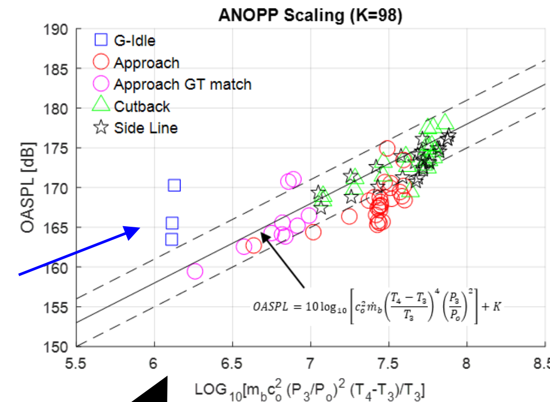
2nd order statics

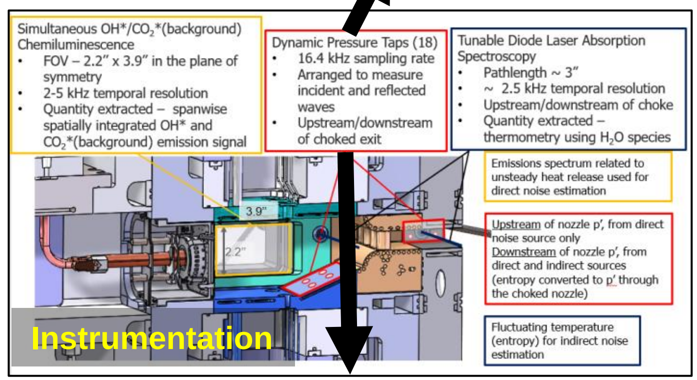




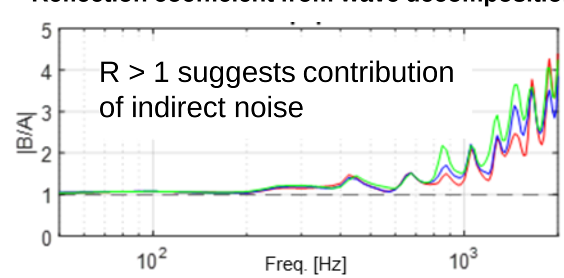
$$R(x_0, y_0, x, y, \tau) = \frac{\overline{q(x_0,y_0,t)q(x,y,t+\tau)}}{\overline{q(x_0,y_0,t)^2}}$$

Dynamic pressure data follows legacy scale law

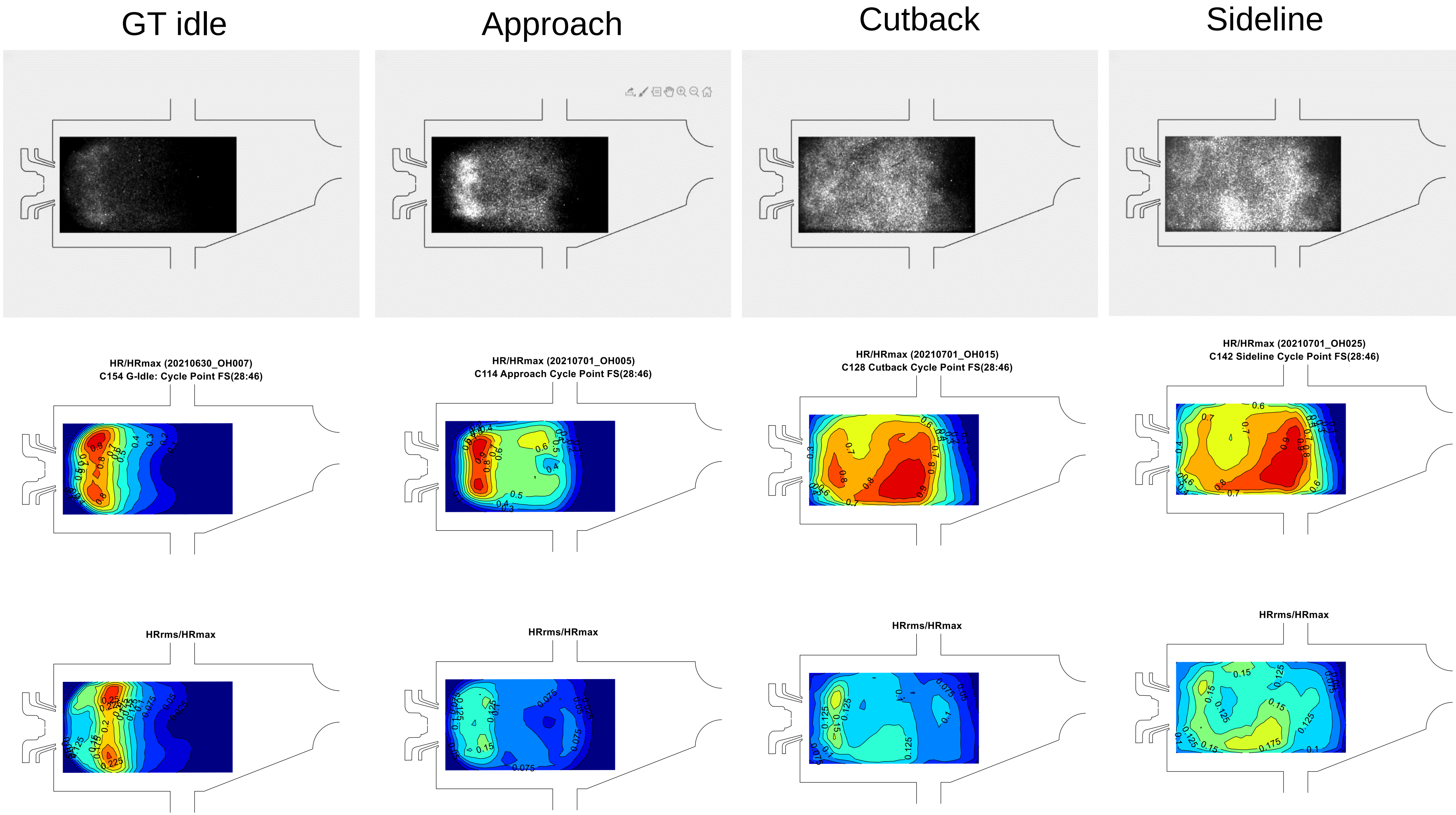




Reflection coefficient from wave decomposition

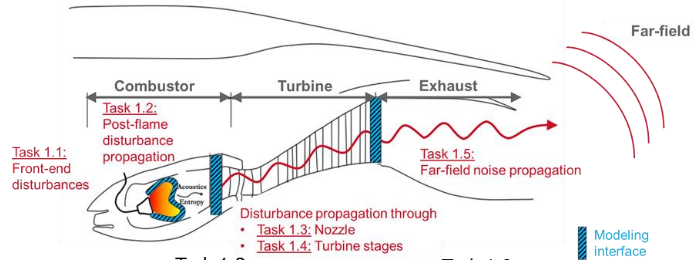


Example Chemiluminescence Data at Cycle Points

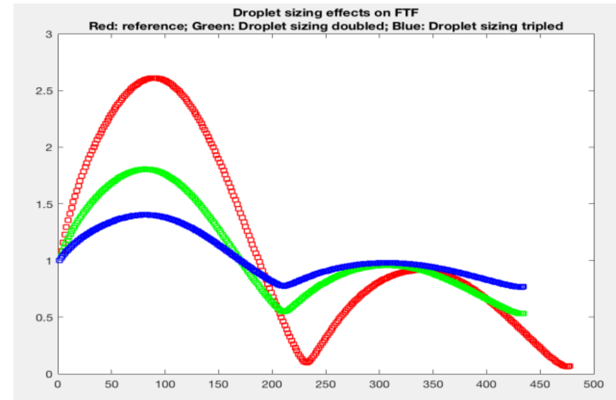


Unsteady heat release field well resolved

Mechanistic Understanding – GT Progress

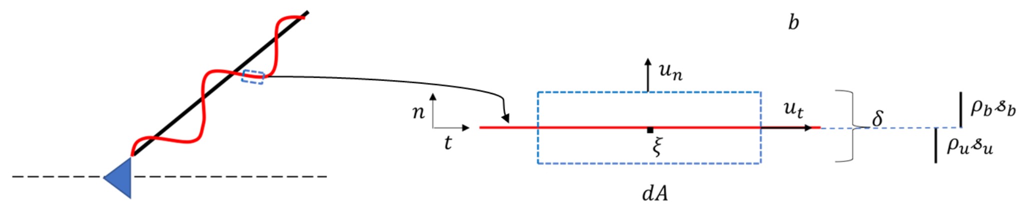


Task 1.1	Task 1.2	Task 1.3
GT Modeling & Simulation: Hydrodynamics, flame dynamics, entropy generation	GT Simulation of post-combustor dynamics	GT simulation of dynamics at jail-bar exhaust



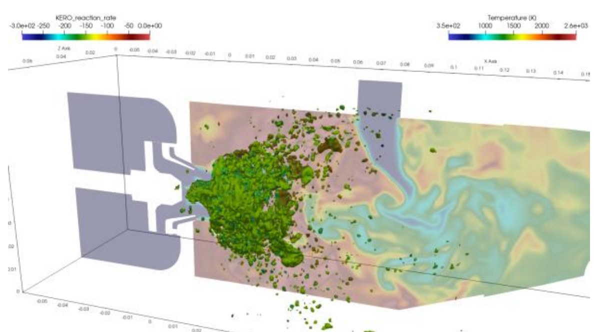
- **Tasks 1.1 Modeling Flame Dynamics and Entropy Generation**
  - Extended flame response framework to model heat release dynamics
  - Extended entropy generation model to include non-isothermal effects
  - Completed study on entropy source terms: specific conditions under which heat release dominate entropy generation (dominant in air breathing liquid fueled systems)

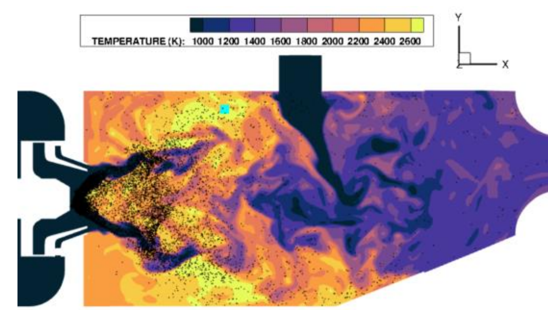
- **Tasks 1.2 Modeling Near-Flame Entropy Evolution**
  - Evolution of entropy disturbances in the immediate downstream of the flame
  - Establish input entropy for RTRC's post-flame entropy transport modeling



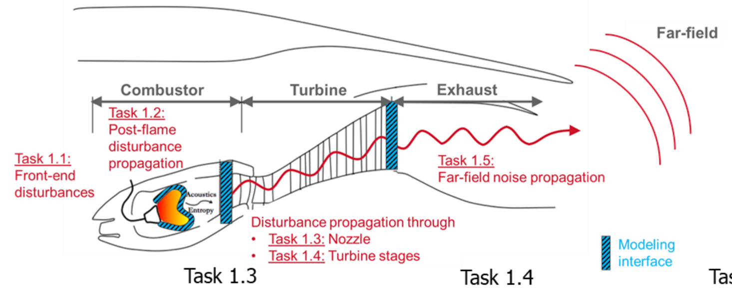
$$(\rho_b S_d^b s_b - \rho_u S_d^u s_u)dA = \frac{\dot{q}''}{T_b}dA$$

- **Tasks 1.1-1.3 High-fidelity simulation**
  - Completed preliminary reacting spray flow in GT rig with swirler
  - On-going post-processing to analyze combustion noise sources
  - Future work to compare with GT rig data





Mechanistic Understanding – RTRC Progress



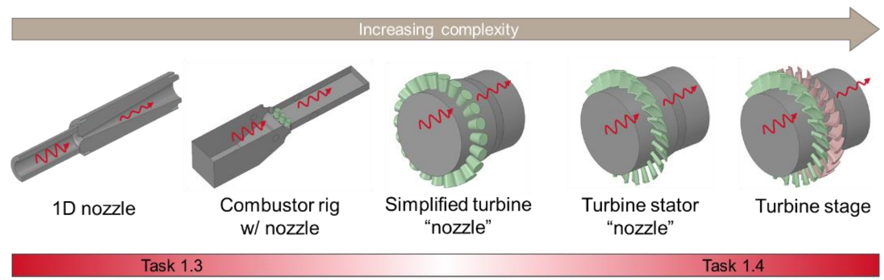
Task 1.2	Task 1.3	Task 1.4	Task 1.5
RTRC Modeling entropy wave transport	RTRC Nozzle Hybrid-LES + Modeling	RTRC Turbine Hybrid-LES + Modeling	RTRC Far-field Sound LEE

➢ Tasks 1.2 Post Flame Combustor Dynamics

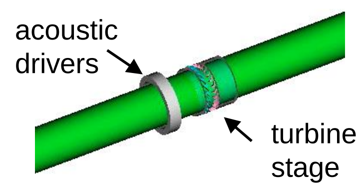
- GT LES and rig data will be used for estimation of direct and indirect noise from combustor
- Entropy wave transport will be used to describe entropy fluctuation changes in the combustor, process for extracting from the LES developed

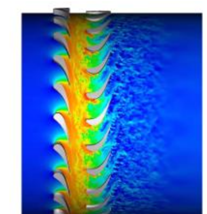
➢ Tasks 1.3 and 1.4 Turbine Nozzle and Stage Interactions

- High-fidelity modeling for simple 1D nozzle to more complex engine relevant combustion/turbine geometries
- Assessment of exiting ROMs (Compact Nozzle Theory and Actuator Disk Theory) to available experimental data, with the application to the RTRC combustor rig w/ nozzle in progress



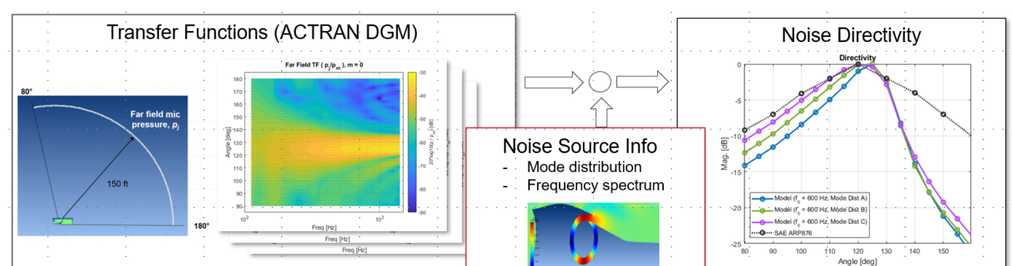
PoliMi turbine rig





➢ 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



(Result show here are for a generic engine geometry)