Physics-based Analysis and Modeling for Supersonic Aircraft Exhaust Noise Project 059D

Lead investigator: Sanjiva K. Lele, Stanford University
Project manager: Sandy Liu, FAA

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ASCENT

Project P59D

Physics-based Analysis and Modeling for Supersonic Aircraft Exhaust Noise

Stanford University

PI: Sanjiva K. Lele, Juan J. Alonso

PM: Sandy Liu

Cost Share Partner(s): Gulfstream

Objective:

- In collaboration with ASCENT partners in Project 59, develop multi fidelity physics-based analyses for supersonic aircraft exhaust noise.
- The main goals are to develop improved jet noise prediction methods and better understand the uncertainty associated with the noise predictions, for a range of engine cycle parameters and operating conditions relevant for civil supersonic aircraft.

Project Benefits:

- Aircraft and engine companies, and organizations such as NASA, FAA, and DoD R&T community would also benefit from the improved methods and tools. Ultimately, supersonic jet noise tools with predictive capabilities can be used to design better noise mitigation systems and to provide estimates of noise for certification studies.

Research Approach:

- In consultation with Project 59 and other project partners in ASCENT define the plans for high-fidelity simulations and jet noise modeling
- Develop and validate high-fidelity jet noise predictions for baseline configurations
- Develop and validate RANS-based jet noise predictions for baseline configurations
- Develop and validate high-fidelity jet noise predictions for configurations with noise mitigation concepts
- Develop and validate RANS jet noise predictions for configurations with noise mitigation concepts

Major Accomplishments (to date):

- Completed LES of NASA Plug20 122Am0pInt and 122Am5pInt nozzles at subsonic + supersonic set points
- Good agreement with experimental acoustics at downstream angles
- Good agreement with near-field PIV measurements
- Quantification of thrust loss from internal mixing
- Proposed a predictive model form of acoustic line source cross spectral density based on eddy-viscosity resolvent analysis

Future Work / Schedule:

- Further investigation of discrepancies between LES + experiments
- Further investigation of ‘excess’ mixing noise

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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.

Introduction

- Long-term objectives
  - Obtain multi-fidelity simulation data (RANS and LES) of high-speed jets from various nozzles of interest
  - Derive predictive reduced-order acoustic models with the numerical datasets
- Short-term objectives
  - Validate LES far-field noise predictions against experimental measurements for a wide array of operating conditions
    - subsonic & supersonic
    - heated & unheated
    - matched & unmatched core/bypass temperature ratio
    - flight stream & no flight stream

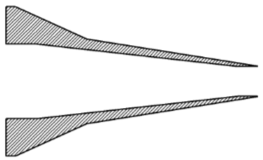
    help us better understand where LES is doing well and where/why it is sometimes struggling
  - Validate LES near-field velocity statistics against experimental PIV measurements

Introduction

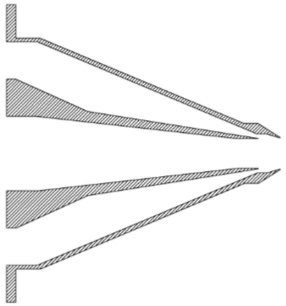
Geometries:

- Georgia Tech

primary nozzle

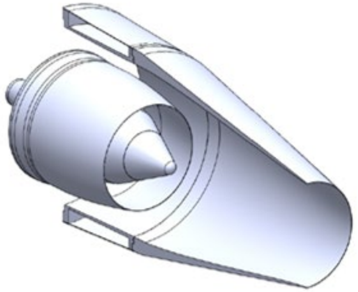


coannular nozzle w/ mixing duct

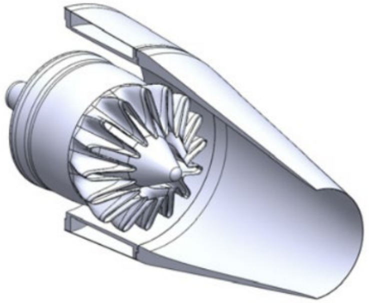


- NASA Plug20

122Am0pInt
splitter w/ internal plug



122Am5pInt
lobed mixer w/ internal plug



Introduction

Operating conditions:

= current project year

Setpoint Matrix

Setpoint	Nozzle	NPRc (core)	NPRb (bypass)	NTRc	NTRb	M_f	FF acoustics	PIV
pr-0p8	GT. primary	1.53	N/A	1	N/A	0.002	✓	
co-0p8	GT. coannular	1.53	1.53	1	1	0.005	✓	
sp7	122Am0pInt	1.856	1.856	1	1	0.002	✓	✓
sp1183	122Am0pInt	1.8	1.8	2.90	1.20	0.3	✓	
sp4200	122Am0pInt	2.0	2.0	1.31	1.31	0.002	✓	✓
sp1200	122Am0pInt	2.0	2.0	3.25	1.2	0.002	✓	✓
sp1183-FMESJ*	122Am0pInt	1.849	1.849	1.606	1.606	0.3		
sp1183	122Am5pInt	1.8	1.8	2.90	1.20	0.3	✓	
sp1203	122Am5pInt	2.0	2.0	3.25	1.20	0.3	✓	✓
sp1233	122Am5pInt	2.3	2.3	3.25	1.25	0.3	✓	

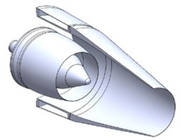
*FMESJ = Fully Mixed Equivalent Single Jet
- equivalent thrust, mass flow, exit area

Schedule and Status

Year 4 accomplishments:

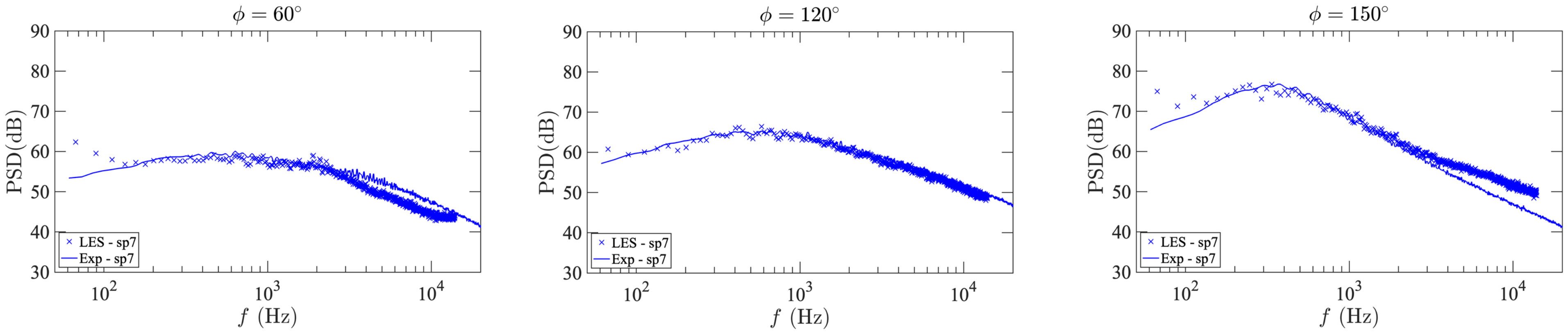
- LES of 122Am5pInt nozzle at sp1203 and sp1233 ✔
- LES of 122Am0pInt nozzle at sp1200 and sp4200 ✔
- Comparison with PIV measurements at sp1203 and sp1200 ✔
- Assessment of LES performance at capturing broadband associated shock noise (SP1233) ✔
- Sensitivity of near and far-field statistics to mesh resolution in internal mixing region ✔

Far-field acoustic results - 122Am0pInt



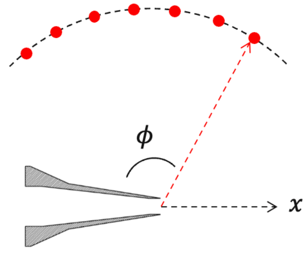
SP70 : NPR = 1.856
NTRc = 1.0
NTRb = 1.0
M_f = 0

SP70 – unheated, matched NTR, no flight stream

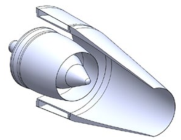


- good agreement across polar angles & frequencies
- small overprediction of high frequency noise at downstream angles

ϕ = angle with respect to the upstream jet axis ($-x$ direction)



Near-field PIV comparison - 122Am0pInt



SP70 : NPR = 1.856
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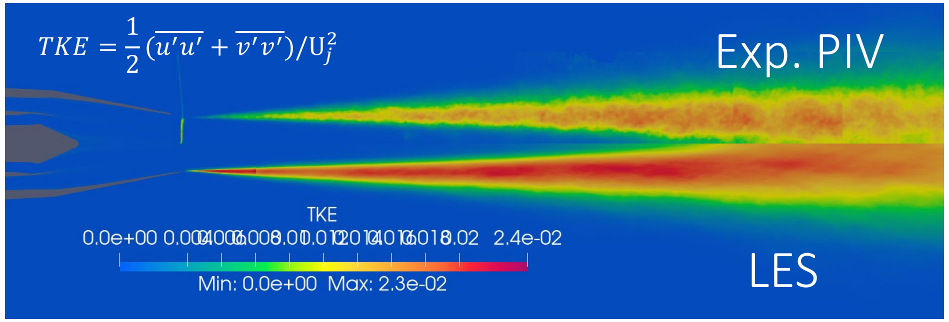
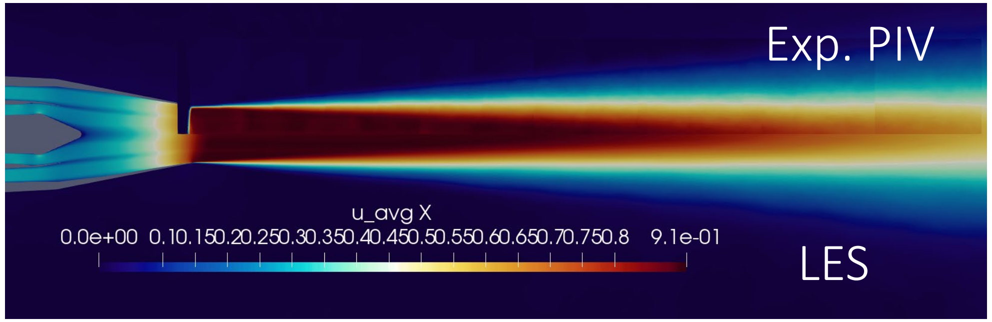
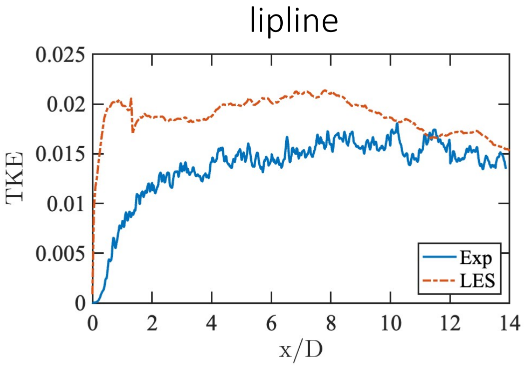
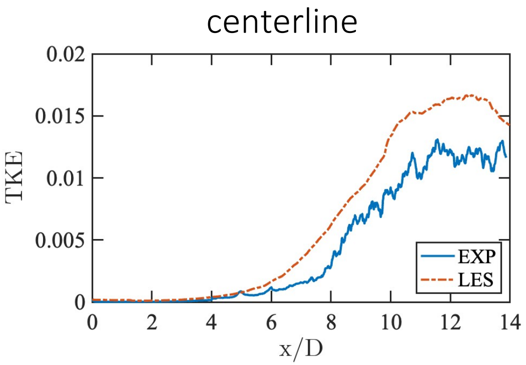
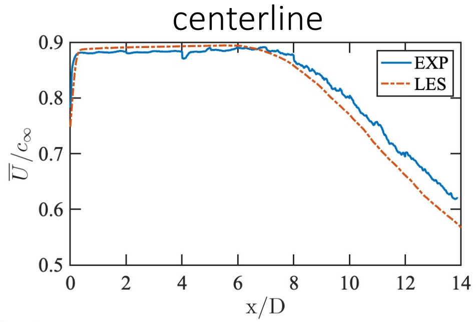
SP70 – unheated, matched NTR, no flight stream

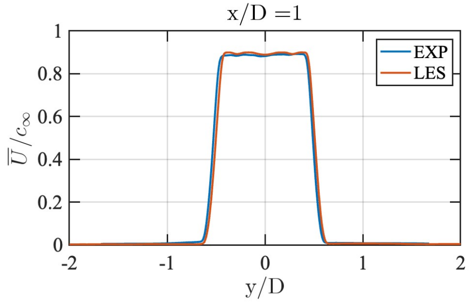


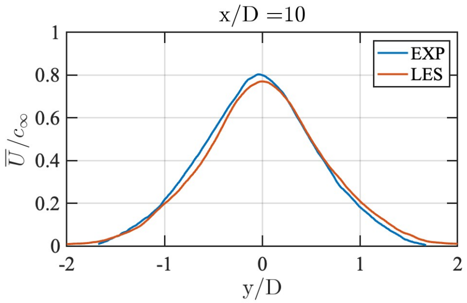




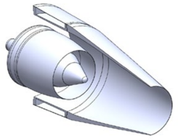






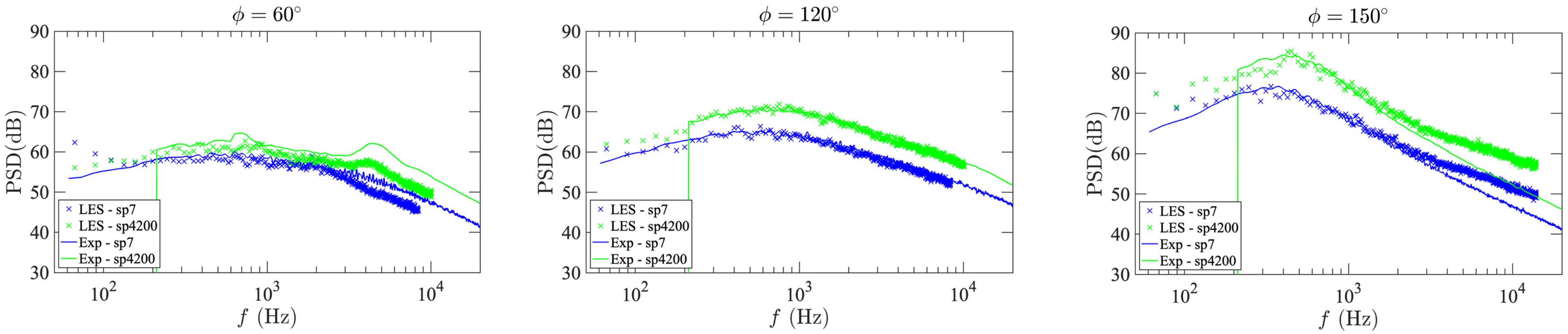


Far-field acoustic results - 122Am0pInt



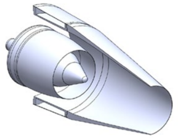
SP4200 : NPR = 2.0
NTRc = 1.31
NTRb = 1.31
$M_f = 0$

SP4200 – heated, matched NTR, no flight stream



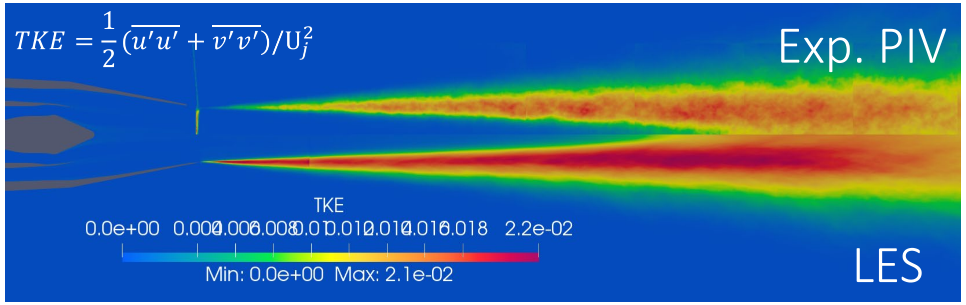
- in general, good agreement with experiments for matched core/bypass temperature with heating
- small overprediction of high frequency noise at downstream angles
- slight underprediction of BBSAN at upstream angles

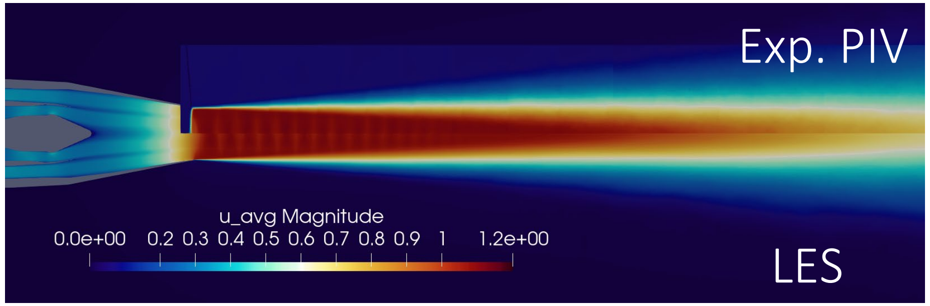
Near-field PIV comparison - 122Am0pInt

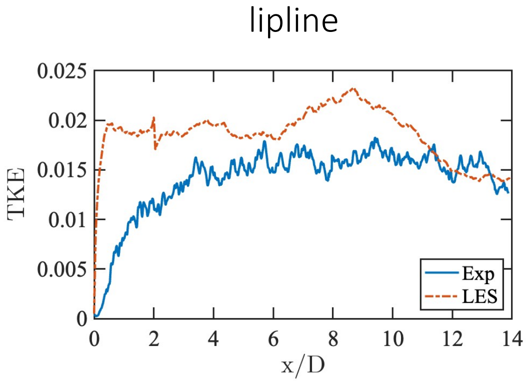


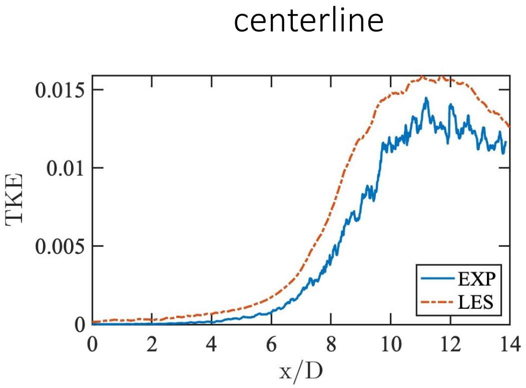
SP4200 : NPR = 2.0
NTRc = 1.31
NTRb = 1.31
$M_f = 0$

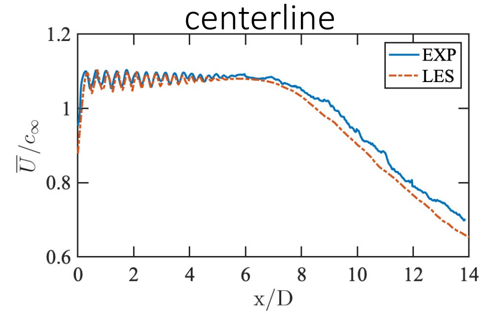
SP4200 – heated, matched NTR, no flight stream

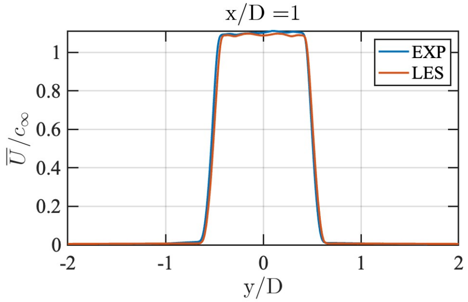


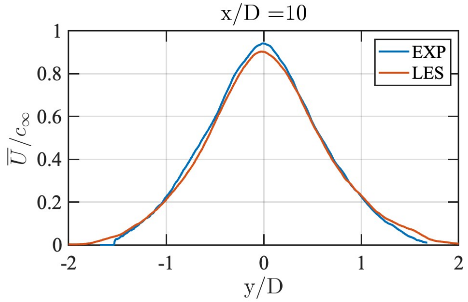




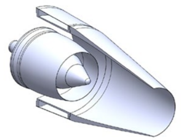






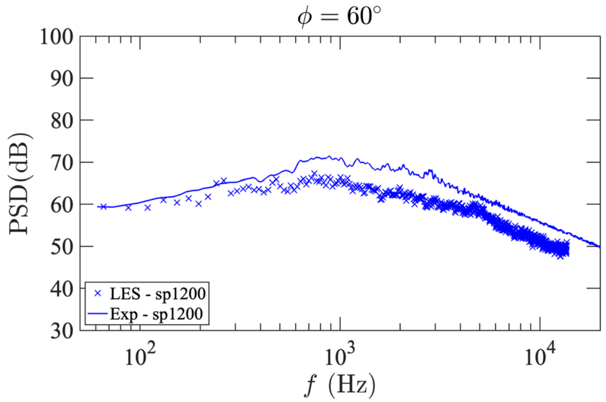


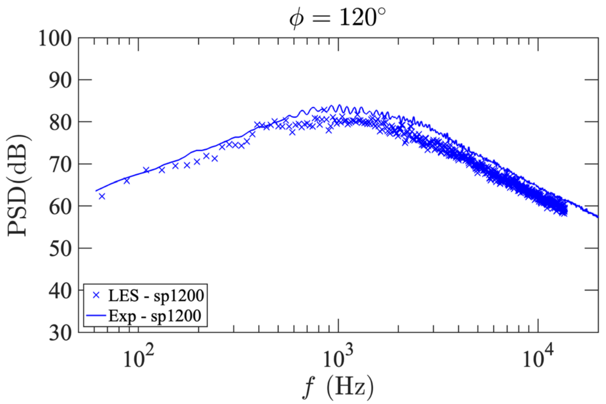
Far-field acoustic results - 122Am0pInt

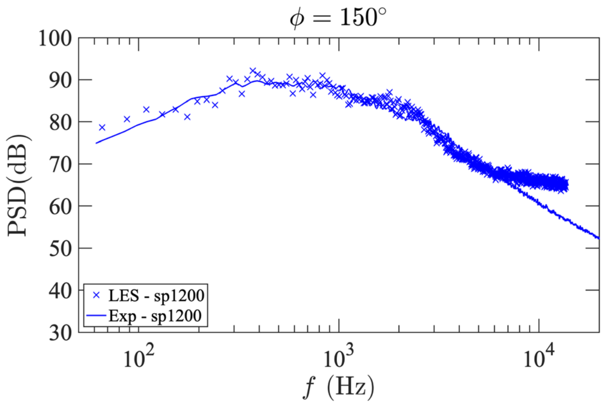


SP1200 : NPR = 2.0
NTRc = 3.25
NTRb = 1.20
M_f = 0

SP1200 – heated, mismatched NTR, no flight stream

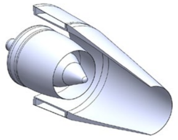






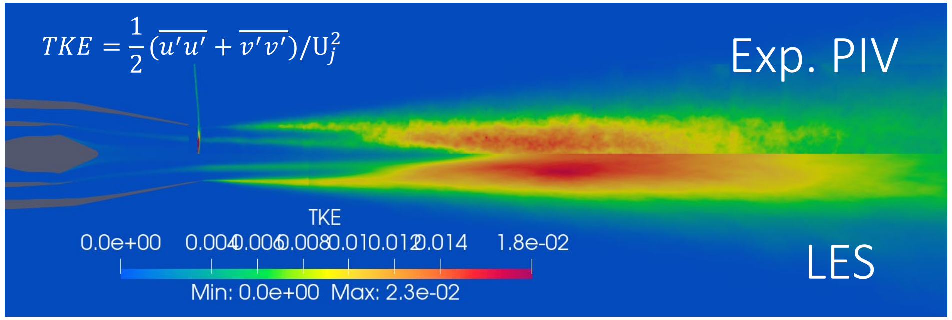
- good agreement for dominant noise at downstream angles
- small overprediction of high frequency noise at downstream angles
- underprediction of noise at sideline & upstream angles

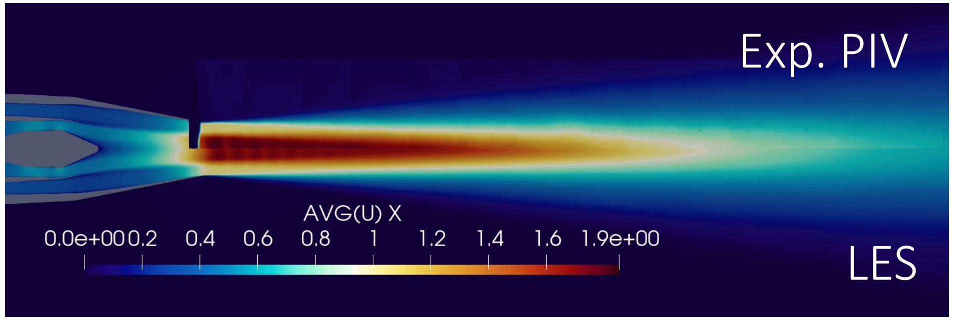
Near-field PIV comparison - 122Am0pInt

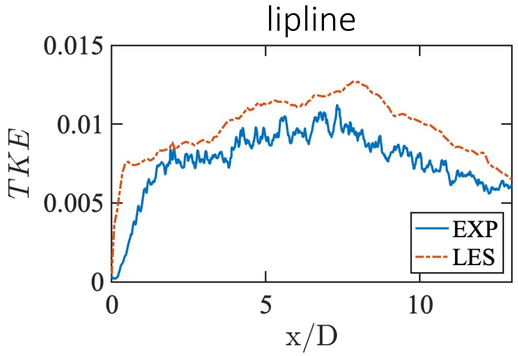


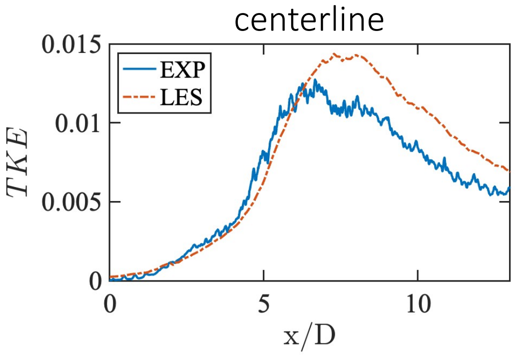
SP1200 : NPR = 2.0
NTRc = 3.25
NTRb = 1.20
M_f = 0

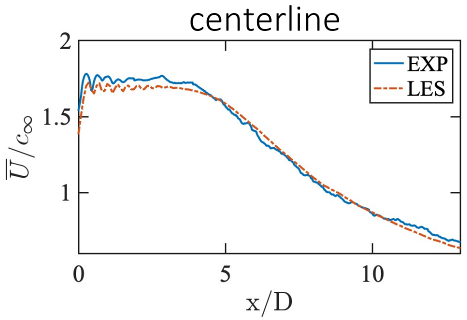
SP1200 – heated, mismatched NTR, no flight stream

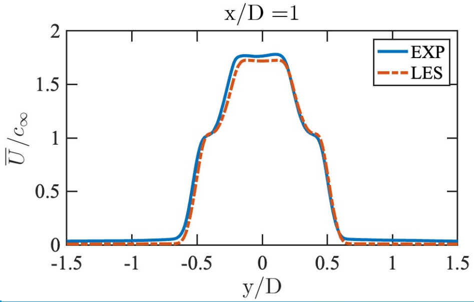


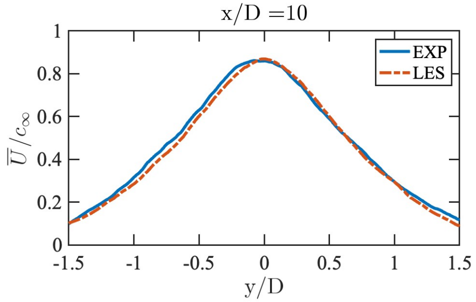




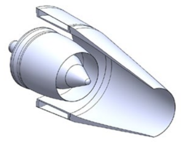






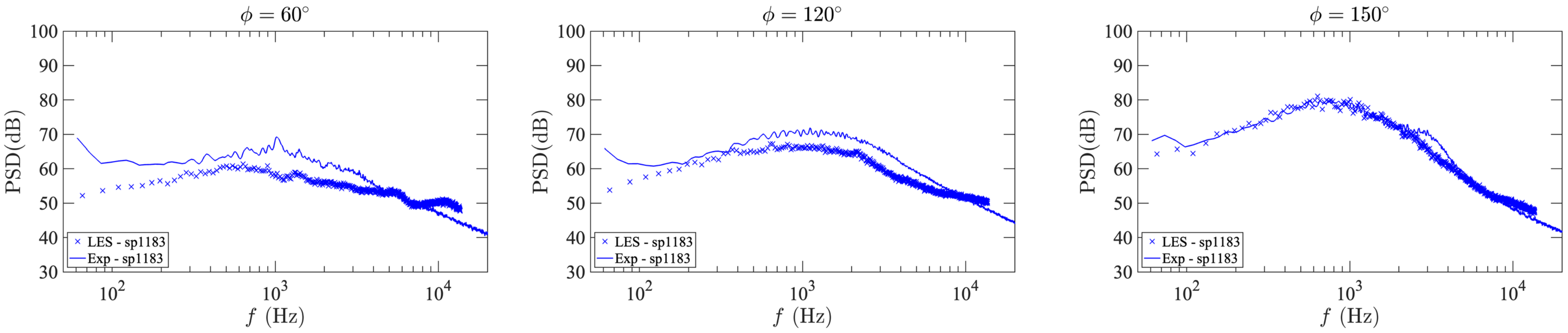


Far-field acoustic results - 122Am0pInt



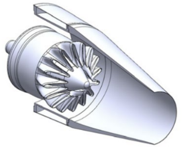
SP1183 : NPR = 2.0
NTRc = 2.90
NTRb = 1.20
M_f = 0.3

SP1183 – heated, mismatched NTR, flight stream



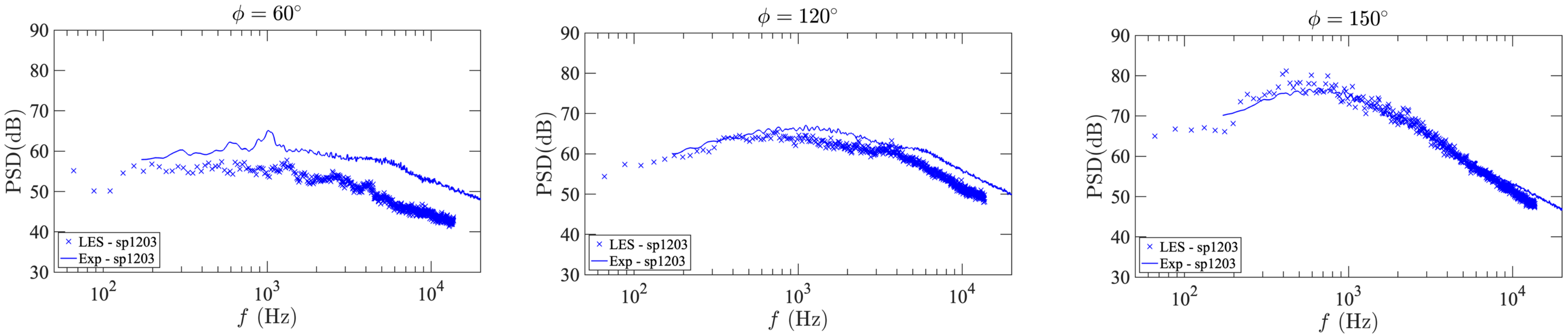
- good agreement for dominant noise at downstream angles
- systematic underprediction across frequencies at upstream & sideline angles
- slightly worse performance compared to static condition (SP1200)

Far-field acoustic results - 122Am5pInt



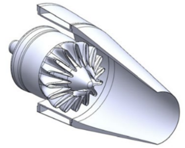
SP1203 : NPR = 2.0
NTRc = 2.90
NTRb = 1.20
M_f = 0.3

SP1203 – heated, mismatched NTR, flight stream



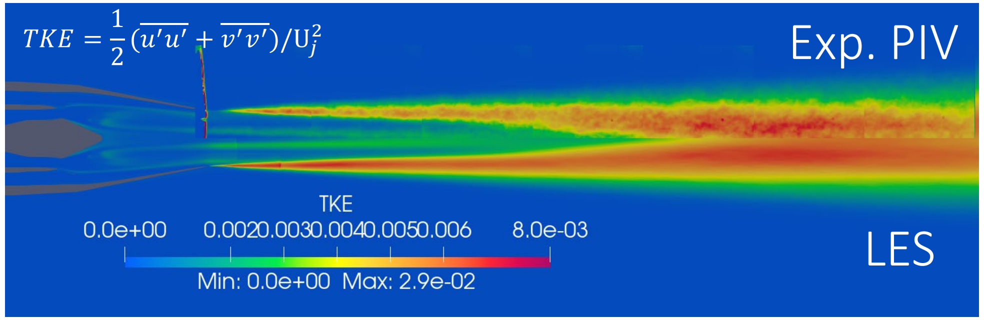
- good agreement for dominant noise at downstream angles
- systematic underprediction across frequencies at upstream & sideline angles
- missing high frequency hump ~5kHz due to internal mixing

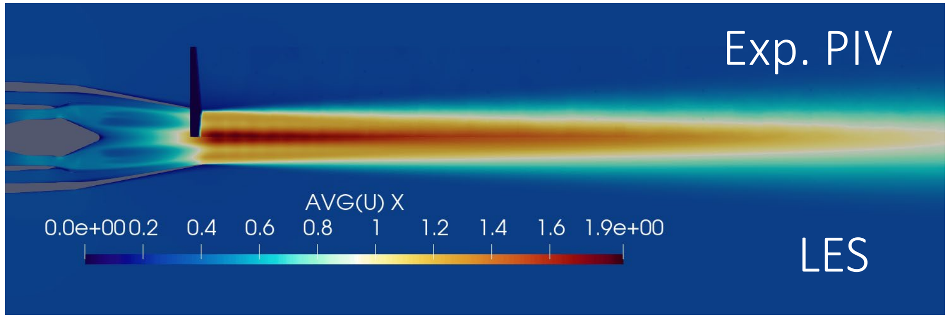
Near-field PIV comparison - 122Am5pInt

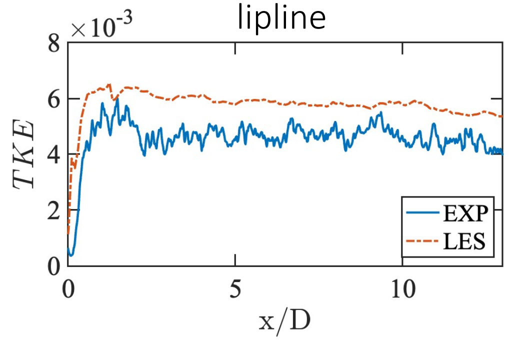


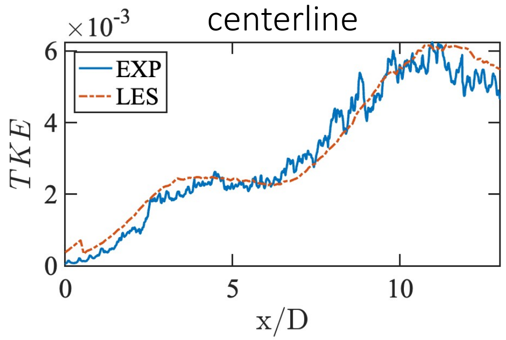
SP1203 : NPR = 2.0
NTRc = 2.90
NTRb = 1.20
M_f = 0.3

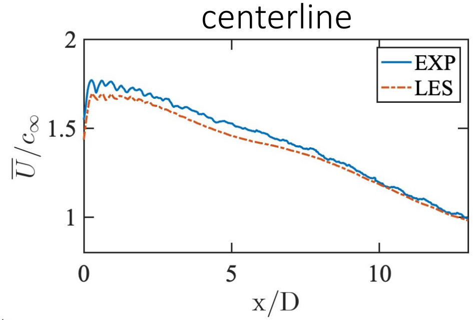
SP1203 – heated, mismatched NTR, flight stream

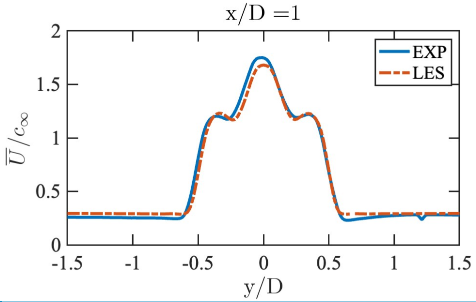


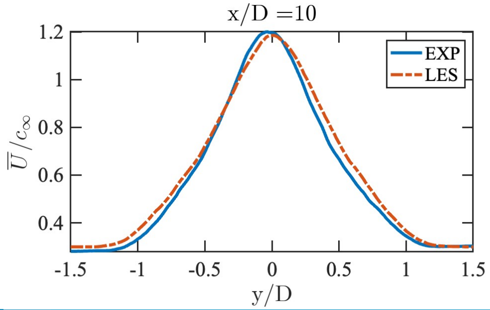




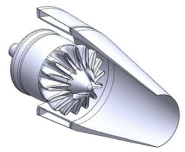






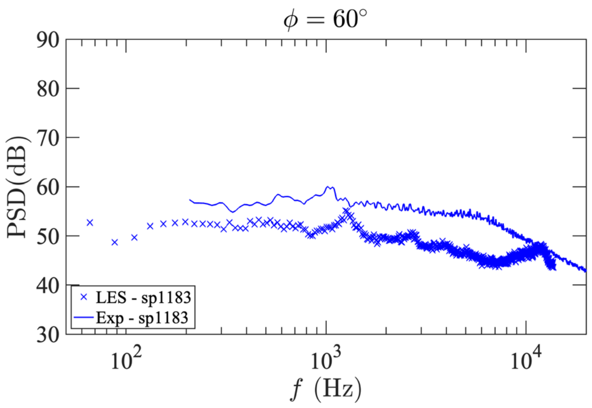


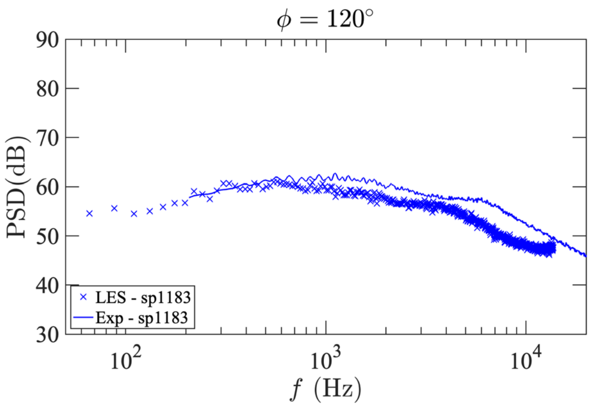
Far-field acoustic results - 122Am5pInt

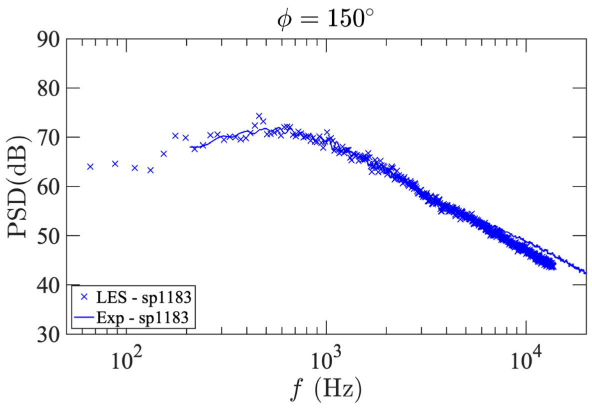


SP1183 : NPR = 2.0
NTRc = 2.90
NTRb = 1.20
M_f = 0.3

SP1183 – heated, mismatched NTR, flight stream

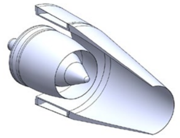






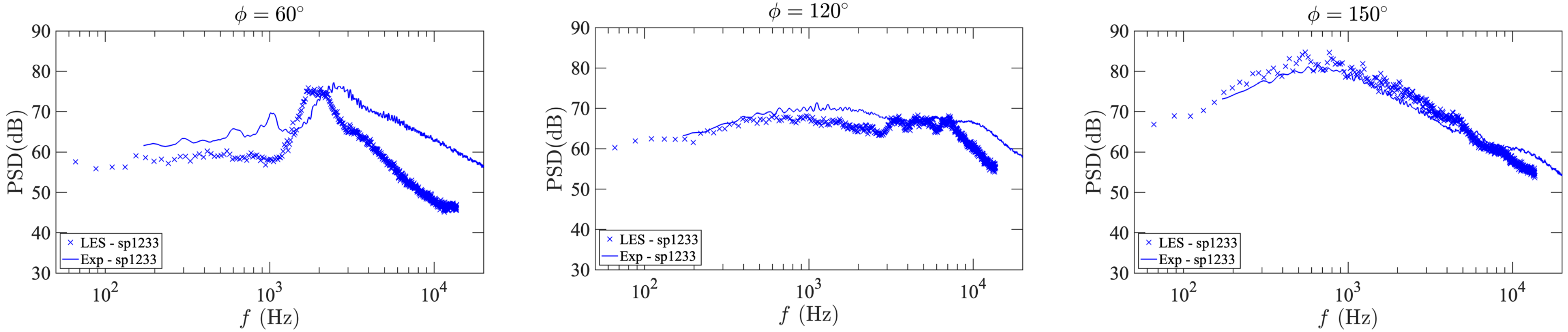
- similar agreement as SP1203
- good agreement for dominant noise at downstream angles
- systematic underprediction across frequencies at upstream & sideline angles
- missing high frequency hump ~5kHz due to internal mixing

Far-field acoustic results - 122Am5pInt

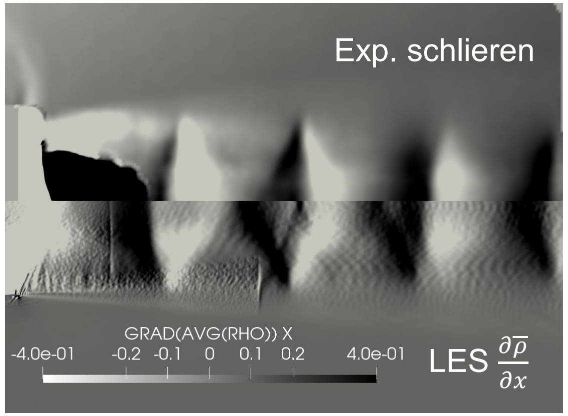


SP1233 : NPR = 2.3
NTRc = 3.25
NTRb = 1.25
M_f = 0.3

SP1233 – heated, mismatched NTR, flight stream, BBSAN



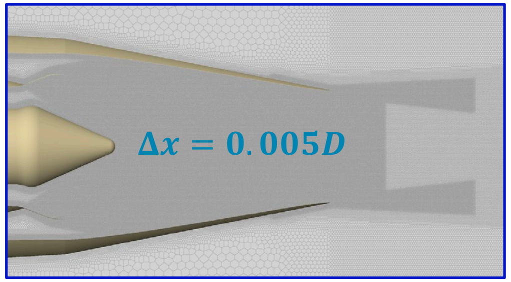
- good agreement with experiments at downstream angles
- BBSAN peak shifted to lower frequencies
  - likely due to slight difference in shock-cell spacing →
- underprediction of high-frequency noise at upstream/sideline angles

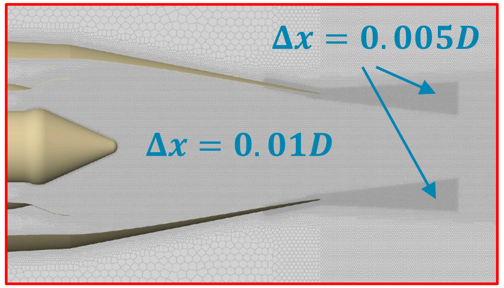


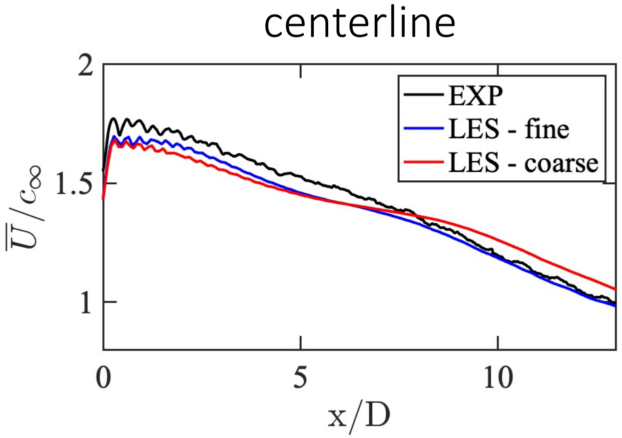
Exploratory efforts towards reconciling discrepancies

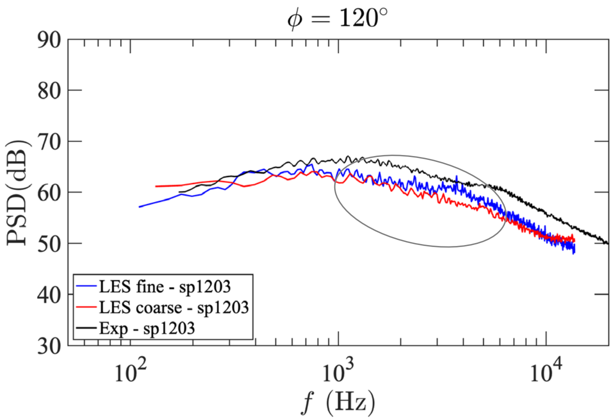
- modifications resulting in negligible change to FF acoustics
  - created more turbulent BL on nozzle exterior for case with coflow (Martin et al., 2024)
  - modified tip of the plug (Wu et al., 2024)
  - extended mesh refinement region + FWH surface downstream
  - modified FWH surface placement to be tighter/looser to jet (Martin et al., 2024)

- coarsening mesh inside the nozzle impacted mean flow exiting the nozzle but only slightly impacted acoustics at sideline angles









Summary

- LES accurately predicts noise across all polar angles & frequencies when core/bypass streams are matched (SP7 & SP4200)
  - mean flow profiles agree well with PIV measurements
  - LES overpredicts TKE in the shear layer
- when core/bypass streams are not matched:
  - LES captures dominant downstream noise radiation across all set points tested (SP1200, SP1183, SP1203, SP1233)
  - Mean flow + TKE profiles are accurately predicted by LES
  - Similar underpredictions of upstream/sideline noise radiation are consistent among all operating conditions
  - LES is not capturing high frequency hump due to internal mixing for 122Am5pInt nozzle
  - BBSAN appears at lower frequencies for SP1233 than experiments
  - changes in modeling choices (mesh/FWH surface/exterior BL) have yet to make significant difference in FF acoustic predictions

Acknowledgements

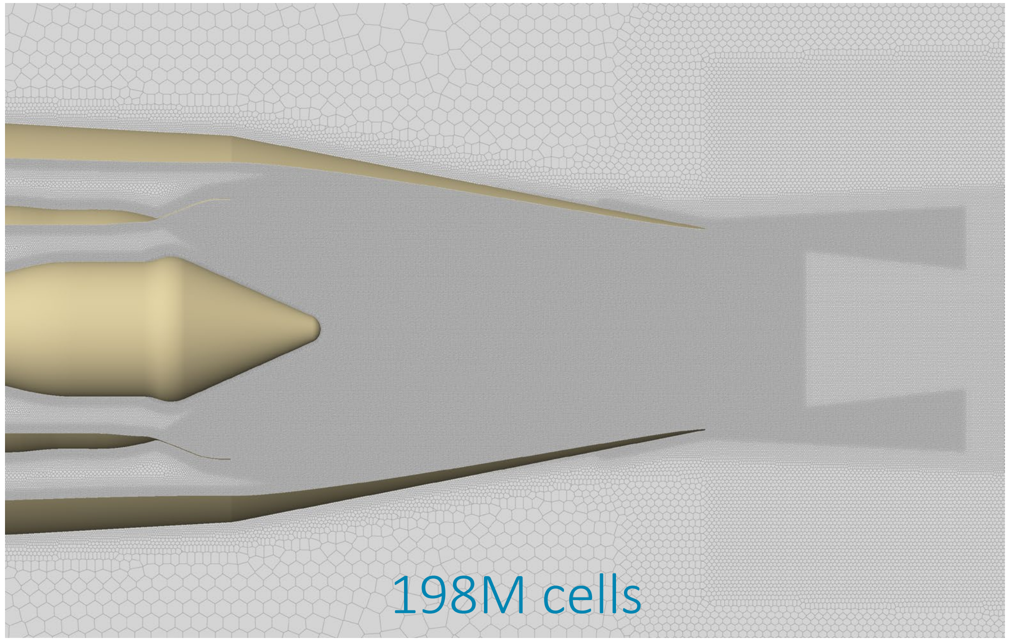
- LES of GT. Nozzles and NASA 122Am0pInt nozzle performed by Gao Jun Wu
- LES of NASA 122Am5pInt + 122Am0pInt nozzles by Olivia Martin
- RANS modeling performed by Tejal Shanbhag

Participants

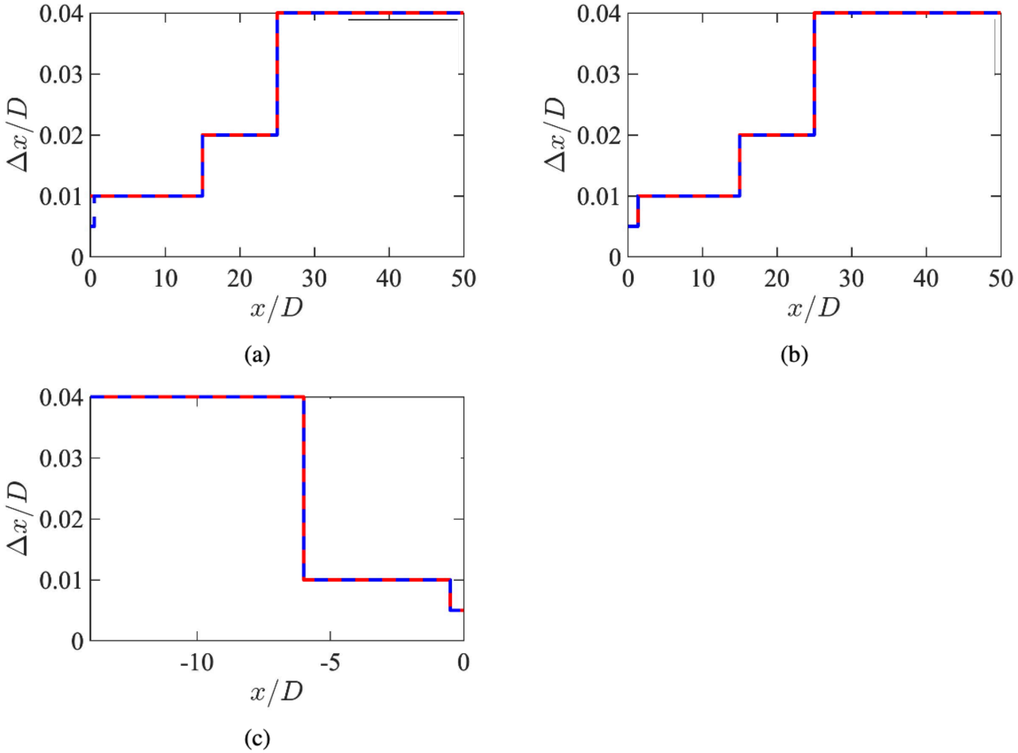
- PI: Sanjiva K. Lele, Juan J. Alonso
- PhD students: Gao Jun Wu, Tejal Shanbhag, Olivia Martin

BACKUP SLIDES

Mesh – 122Am5pInt Nozzle

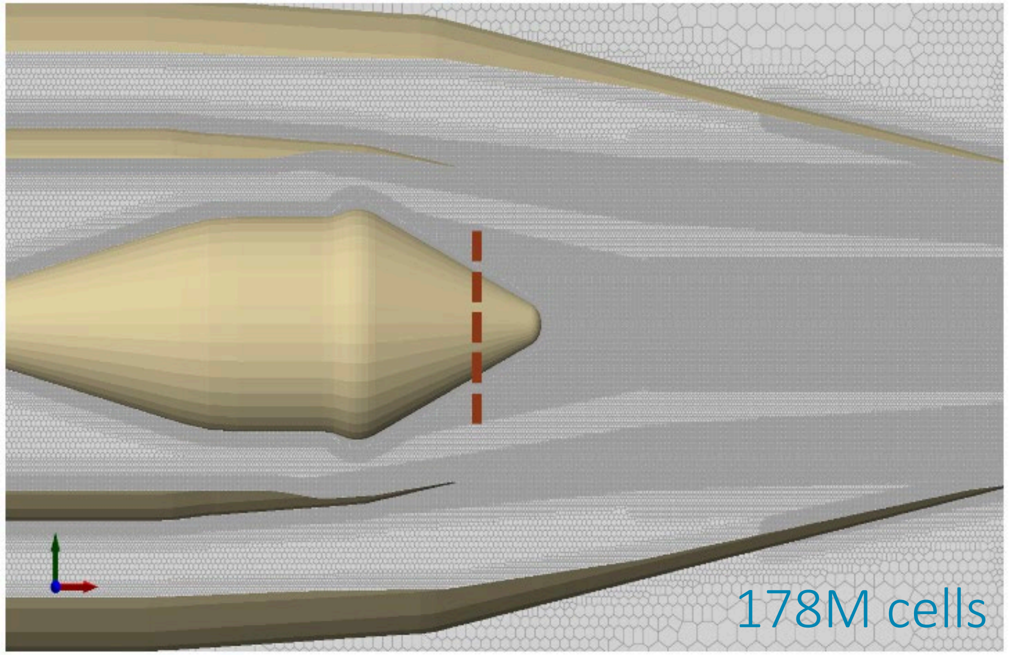


- voronoi-based mesh generation (Bres et al., 2018)
- isotropic polyhedral cells
- finest resolution: $\Delta x_{min} = 0.005D$



Mesh resolution along the (a) jet centerline, (b) lipline, and (c) outer surface of the nozzle

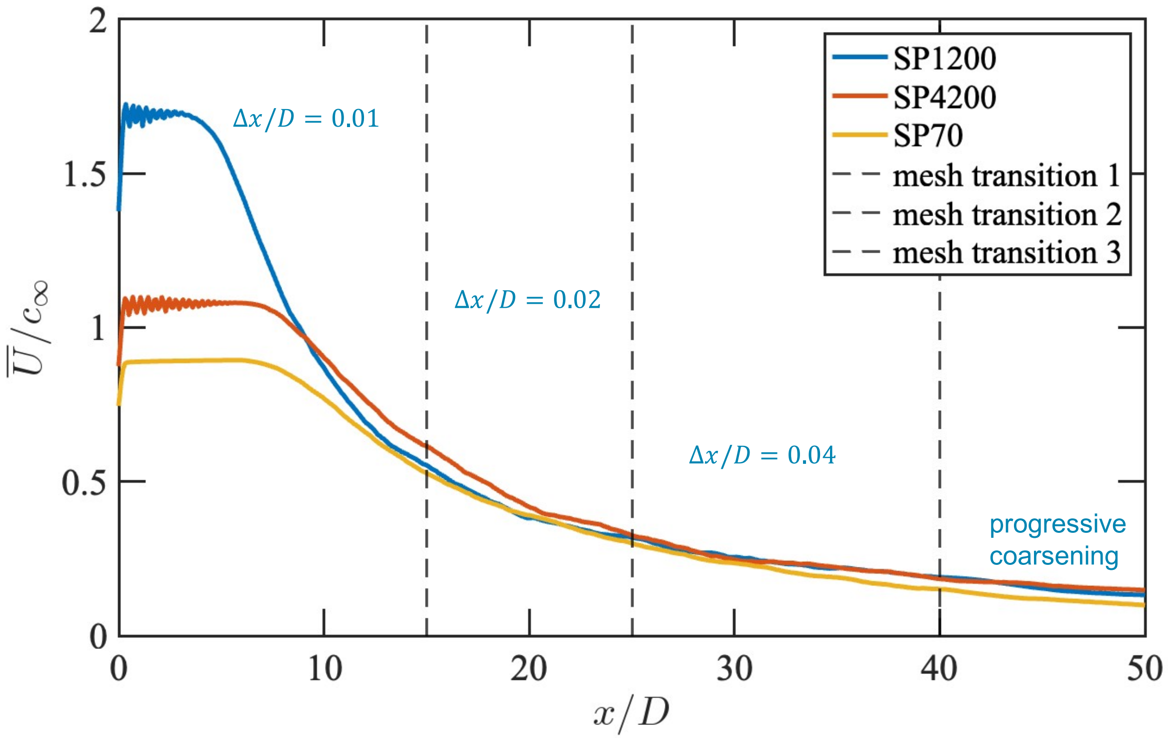
Mesh – 122Am0pInt Nozzle



- voronoi-based mesh generation (Bres et al., 2018)
- isotropic polyhedral cells
- finest resolution: $\Delta x_{min} = 0.005D$

U_j comparison across cases

122Am0pInt nozzle



122Am5pInt nozzle